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MONITORING, CONTROL AND SAFETY EQUIPMENT FOR A NUCLEAR REACTOR OF THE SWIMMING-POOL TYPE

I. GENERAL DESCRIPTION

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On 28 June 1957 a nuclear reactor was put into operation for the first time in the Netherlands, at the exhibition "Het Atoom" at Amsterdam. While the reactor is of American manufacture (A.M.F. ATOMICS, New York), the Netherlands industry played a considerable part in its planning and installation. Most of the electronic control and safety equipment, for example, was supplied by Philips.

Part I of an article on this equipment is printed below and contains a brief explanation of the functioning of a nuclear reactor and a general description of the apparatus. Part II, to be published in a later issue, will deal in detail with certain components, including one of the neutron flux meters, the gamma-ray indicator and the safety amplifier.

The "nucleus" of the exhibition "Het Atoom" [1]), which was held in Amsterdam during the summer months of 1957, was undoubtedly the experimental nuclear reactor that was shown in operation (*fig. 1*). The reactor, which was designed and supplied by A.M.F. ATOMICS Inc., New York, a subsidiary of the American Machine and Foundry Inc., is soon to be transferred to the Technische Hogeschool at Delft.

The principal data concerning this reactor are given below (reproduced by courtesy of A.M.F. ATOMICS). Some of the terms occurring here and also further in the article are explained under the heading "Operation of a nuclear reactor" (see pp. 246-248).

Type:
 "Swimming Pool" type, i.e. the reactor core is set up in a water-filled tank, the water having the three functions mentioned below. The tank is in the form of a well (7 m deep, 3 m diameter; see *fig. 2*).

Power:
 max. 100 kW (at the Exhibition the reactor was operated at max. 10 kW).

Fuel:
 enriched uranium (20% U^{235}).

Moderator:
 ordinary (not heavy) distilled water.

Coolant:
 the same water as above.

Shielding:
 the same water as above, and concrete.

Dimensions of reactor core:
 $38 \times 45 \times 60$ cm.

Neutron flux inside reactor core:
 max. 10^{12} neutrons per cm^2 and per second.

Coarse control and safety elements:
 four shim and safety rods of boron carbide (three at the Exhibition).

Fine control:
 one control rod of stainless steel.

Excess reactivity:
 0.5% at the Exhibition (will be more later).

Max. control effect of all rods together:
 12.5%.

The latter two items indicate that the factor k by which the number of neutrons rises or falls from one generation to another amounted at maximum

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[1]) Atomics and Nuclear Energy **8**, 289, 1957 (No. 8); Nuclear Power **2**, 334, 1957 (No. 16).

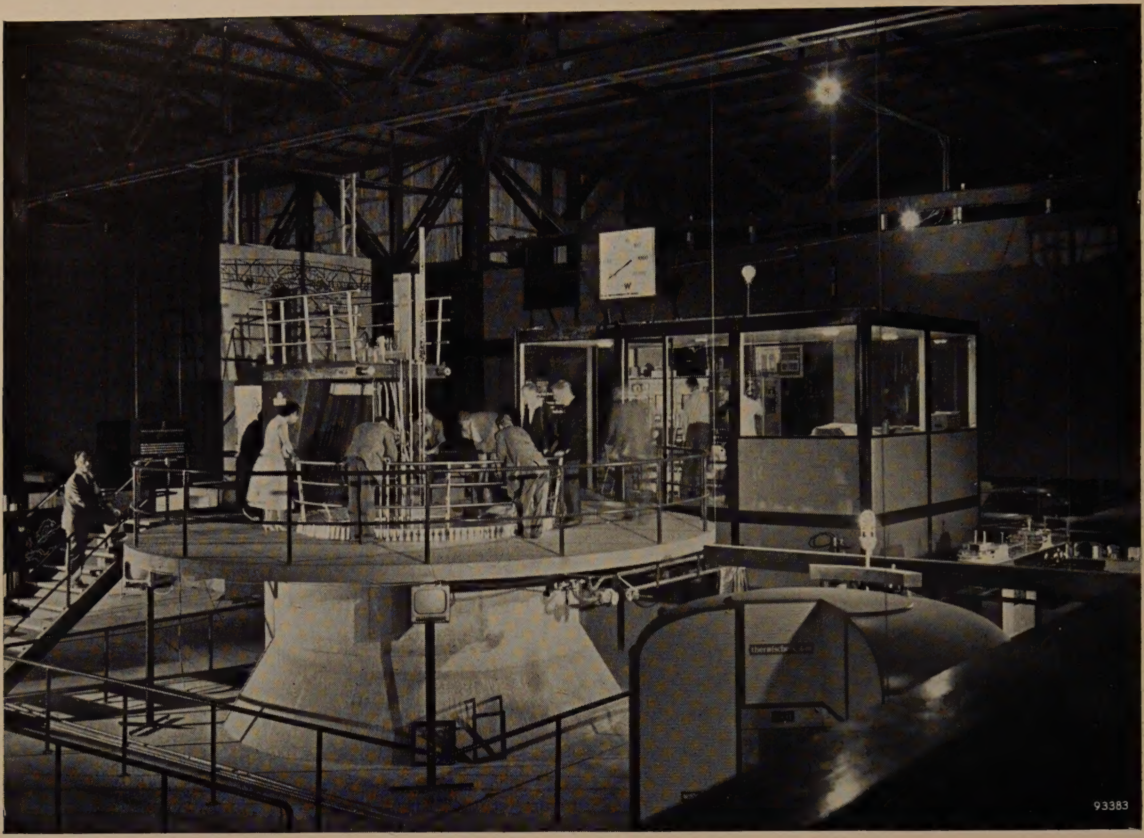

Fig. 1. Experimental nuclear reactor of the swimming-pool type at the exhibition "Het Atoom" in Amsterdam (Schiphol Airport). The photograph shows the upper part of the cylindrical tank, around which a platform has been fitted for visitors. The monitoring, control and safety equipment is installed in the cabin in the background.

to 1.005 (all rods up) and at minimum to 12.5% less, i.e. about 0.9 (all rods down).

The reactor core is near the bottom of the tank (fig. 2). The fuel elements, which contain altogether 18 kg of uranium, are entirely sheathed in aluminium to prevent the entry of highly radioactive fission products into the water. The water can circulate freely between the fuel elements. Some of the elements are designed to allow a safety or control rod to be moved up and down inside them. This is done with the aid of servomotors mounted on a platform above the tank. The water is kept circulating by a pump. It is passed through a mineral extractor (ion exchanger) to remove as many as possible of the mineral constituents which, in the long run, would "poison" the moderator.

Operation of a nuclear reactor

We shall first briefly discuss the operation of a nuclear reactor which uses uranium as "fuel"; in doing so we shall clarify some of the terms mentioned in the course of this article.

The operation of a uranium reactor is based principally on the properties of the uranium isotope U^{235}. Natural uranium contains only about 0.7% U^{235} and more than 99% U^{238}. Use is often made of "enriched" uranium, the U^{235} content of which is, for example, 20%.

Fission of U^{235} nuclei

After capturing a neutron, a U^{235} nucleus can split into two (rarely, three) fragments. The fragments are mostly unequal in size, the one having a mass number of about 95 and the other about 140. With each fission an energy of some 200 MeV is released, largely in the form of the kinetic energy of the fission fragments. By the intermediary of a coolant, for example, this energy can be extracted from the reactor and put to use. A small proportion of the fission energy is released as gamma radiation; a shield, consisting perhaps of water and concrete, ensures adequate absorption of this radiation.

The fragments of a single fission produce, on an average, two or three neutrons, and these in their turn can be used to split other U^{235} nuclei and so to keep the process self-sustaining. However, the neutrons liberated from the fission products have very high velocities (energy in the order of 1 MeV), and in uranium having 20% U^{235} such fast neutrons are not able to split U^{235} nuclei in sufficient numbers. To do so they must be slowed down to "thermal" velocities corresponding to about 0.03 eV. (This is expressed by saying that the U^{235} nucleus has a small effective cross-section for fast neutrons and a large one for "thermal" neutrons.) The slowing-down of the fast neutrons in the reactor, without excessive neutron absorption, is performed by a "moderator". This consists of a substance (e.g. graphite, ordinary or heavy water) which is mixed with the uranium, or which surrounds it, in such a way that the fast neutrons enter it and lose velocity by collisions. After only 18 collisions with H atoms, for instance, a neutron with an initial energy of 1 MeV has become a thermal neutron.

Chain reaction

A number of the neutrons liberated by nuclear fission are lost; some escape from the reactor, others are absorbed in U^{238} nuclei, in the moderator, in the fission products or in deliberately introduced neutron-absorbent material (see below). It has proved readily possible, however, to create conditions in which a sufficient number of the liberated fast neutrons can be slowed down to thermal velocities in order to sustain the reaction (chain reaction). Once these conditions are realized, the reaction can set in spontaneously, for there is usually a thermal neutron already present (e.g. from cosmic radiation) which can serve as the "trigger". To have a measurable quantity from the start, however, an artificial source of neutrons is always used in practice for supplying the initial neutrons.

The larger the reactor, the smaller is its surface area in relation to its volume and thus the smaller in proportion is the chance of neutrons escaping. There is, in fact, a *critical size*, below which no chain reaction can take place in the reactor because of excessive neutron losses. The magnitude of this critical size is strongly dependent upon a variety of circumstances, such as the configuration, the nature of the moderator, the U^{235} content and the temperature.

Neutron conservation

In a working reactor neutrons are constantly being liberated and constantly absorbed or captured. We can therefore speak of neutron generations having a certain average lifetime. An important quantity is the *multiplication factor k*, which is the ratio of the number of neutrons in a given generation to the number in the preceding generation. The condition for a just self-sustaining chain reaction (stationary state) is that k be equal to unity. To start a reactor, k must be greater than unity; a very small excess, for instance 0.1%, i.e. $k = 1.001$, may be sufficient.

Although two to three new neutrons are produced with each fission, so that if there were no losses the factor k would be 2 or 3, the maximum value that k can reach in an actual reactor is usually not more than 1.01. The reasons for this are the following:

1) Escape of neutrons from the reactor.
2) Absorption of neutrons in the moderator, in the fission products and in U^{238}, in particular resonance absorption during the slowing-down process in the moderator: the chance that neutrons having an energy of 6.5 eV are captured by U^{238} nuclei ("resonance") is not to be neglected.

The loss of neutrons is slightly offset by the fact that a few of the neutrons not yet slowed down also cause the fission of U^{235} and U^{238} nuclei, giving rise to more than one fast neutron per fission. This is the so-called fast fission effect.

When a state is reached where k is greater than unity — which is more easily reached the richer the uranium is in U^{235} — the neutrons then continuously increase in number, and so therefore do the number of fissions per second and the power

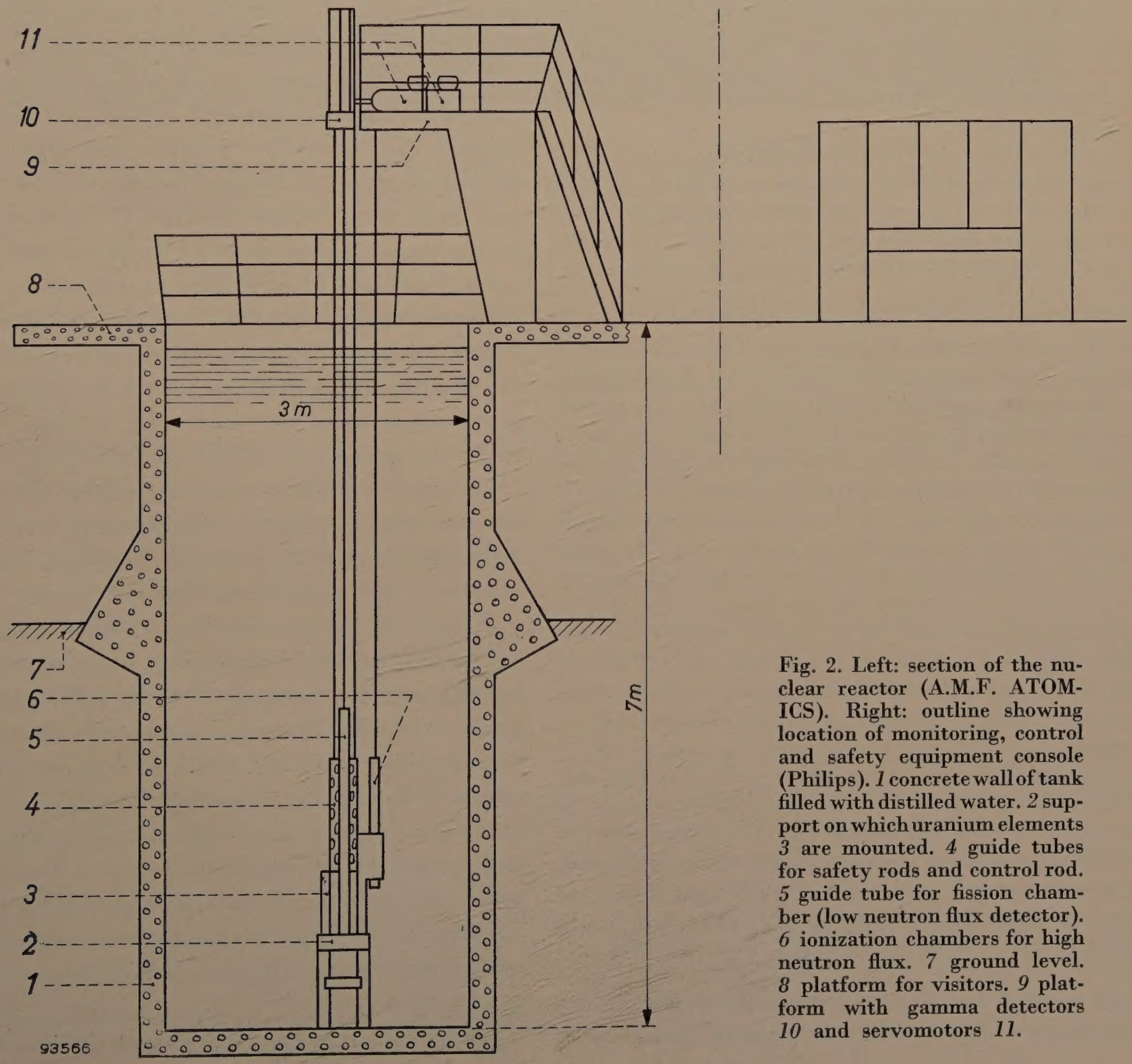

Fig. 2. Left: section of the nuclear reactor (A.M.F. ATOMICS). Right: outline showing location of monitoring, control and safety equipment console (Philips). *1* concrete wall of tank filled with distilled water. *2* support on which uranium elements *3* are mounted. *4* guide tubes for safety rods and control rod. *5* guide tube for fission chamber (low neutron flux detector). *6* ionization chambers for high neutron flux. *7* ground level. *8* platform for visitors. *9* platform with gamma detectors *10* and servomotors *11*.

delivered by the reactor. The time required for the power to increase by a factor e — the time constant — is known as the "period" of the reactor.

Control

It is essential to be able to control the rate of the reaction in a nuclear reactor. Since the fission itself and the subsequent slowing-down in the moderator take place in such an extremely short time, it might be thought that each chain reaction started would spread too rapidly to allow timely intervention by any regulating mechanism and hence would make it impossible to control the reaction. The fact that control is possible is due to the circumstance that not all the neutrons are immediately liberated during the fission. Of the total neutrons liberated, 99% are indeed "prompt" in this sense, but the gradual release of the remainder can still be observed for minutes after a fission process. These "delayed" neutrons make it possible to control the reaction by mechanical, that is to say relatively slow, means.

As we have seen, with each fission an energy of about 200 MeV is liberated. The power delivered by a reactor is proportional, then, to the number of fissions per second. This number in its turn is proportional to the number of thermal neutrons present. In order to measure (and also to control) the power of the reactor it therefore suffices to measure the number of thermal neutrons. This is possible because the neutrons are in continuous motion through the reactor. The product of the number of thermal neutrons per unit volume and their average velocity (this velocity is not dependent on the power developed by the reactor) is called the *neutron flux* (N). This product, which is proportional to the reactor power, is one of the main quantities constantly monitored in a reactor and is employed for control purposes.

If u is the number of U^{235} nuclei per unit volume, σ the effective cross-section of a U^{235} nucleus for thermal neutrons, and V the volume of the reactor, then $Nu\sigma V$ is the number of fissions occurring per unit time. With each fission 200 MeV is released, i.e. 3.2×10^{-11} joule. The power developed, P, is therefore:

$$P = Nu\sigma V \times 3.2 \times 10^{-11} \text{ watt.}$$

With a reactor in the stationary state the multiplication factor k is, by definition, precisely equal to 1. Naturally, this state can never be maintained exactly; the number of neutrons (hence the neutron flux and the power) gradually increases or decreases. In order nevertheless to keep the power within definite bounds it is necessary to have some means of varying k. For this purpose use is made of one or more rods of a material that absorbs neutrons (e.g. cadmium, boron, iron). By varying the depth to which these *control rods* are inserted into the reactor (by means of servomotors, for example) the neutron losses and thus the k factor can be varied. Some of the rods ("shim" rods) are usually employed for making coarse adjustments, being so positioned that k is equal to unity when the others, the control rods proper, are in their middle position; this makes fine control possible over a maximum range on either side. The shim rods are also sometimes used as "safety rods" which, in case of emergency, are quickly plunged into the reactor to bring it to a standstill. Control operations are usually carried out automatically, utilizing automatic control techniques.

A controlled chain reaction, with graphite as moderator and control rods of cadmium, was first achieved under the direction of Fermi in the University of Chicago in December 1942.

Some details of the fuel consumption and reaction products of a nuclear reactor are given in the appendix to this article.

Survey of the instruments required

To ensure the efficient functioning of the reactor certain quantities must be continuously measured (and some recorded) and it must be possible to operate the servomotors manually as well as by automatic control. The quantities measured are:

a) the neutron flux (at five points in the reactor core);
b) the temperature of the water (at three points);
c) the position of the control rod and of the safety rods;
d) the gamma radiation (at two points above the water and at one point near the ion exchanger).

These quantities are converted by various types of detectors into electrical signals which can be read directly from meters. The generated power, which is proportional to the neutron flux, and the "period" (time constant), which is derived from the rate of change of the neutron flux, can also be read from meters. A too short period indicates that the neutron flux (and hence the power) is increasing too rapidly.

The reactor power is regulated by moving the control rod up or down by means of a servomotor.

Of extreme importance are the provisions made for safety. There is no question of an atomic explosion; what must be guarded against are rather such dangers as excessive gamma radiation in the surroundings and damage to the reactor core by too high local temperatures. If such a danger threatens, an alarm must be given at once and the reactor put out of operation as quickly as possible ("scram"). This is done in the following way. The safety rods are suspended from their driving mechanism by means of electromagnets. If the reactor period is too short, the neutron flux too high, the gamma radiation excessive, or if certain other undesirable conditions arise, the current through the magnets is immediately cut off. The rods then drop to their lowest position, where they absorb so many neutrons that the reactor stops.

Nearly all the measuring, control and safety equipment for this reactor was supplied by Philips to the specifications of A.M.F. ATOMICS. The equipment, which is largely electronic, is mounted on five standard racks and a control desk, arranged as a console (*fig. 3*). The three middle racks contain the most important instruments, including the recording potentiometers ²) for the neutron flux. The two photos in *fig. 4* show the five racks from the rear; amongst the things visible in these views are the mains voltage stabilizer and the complete relay

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²) H. J. Roosdorp, An automatic recording potentiometer for industrial use, Philips tech. Rev. **15**, 189-198, 1953/54.

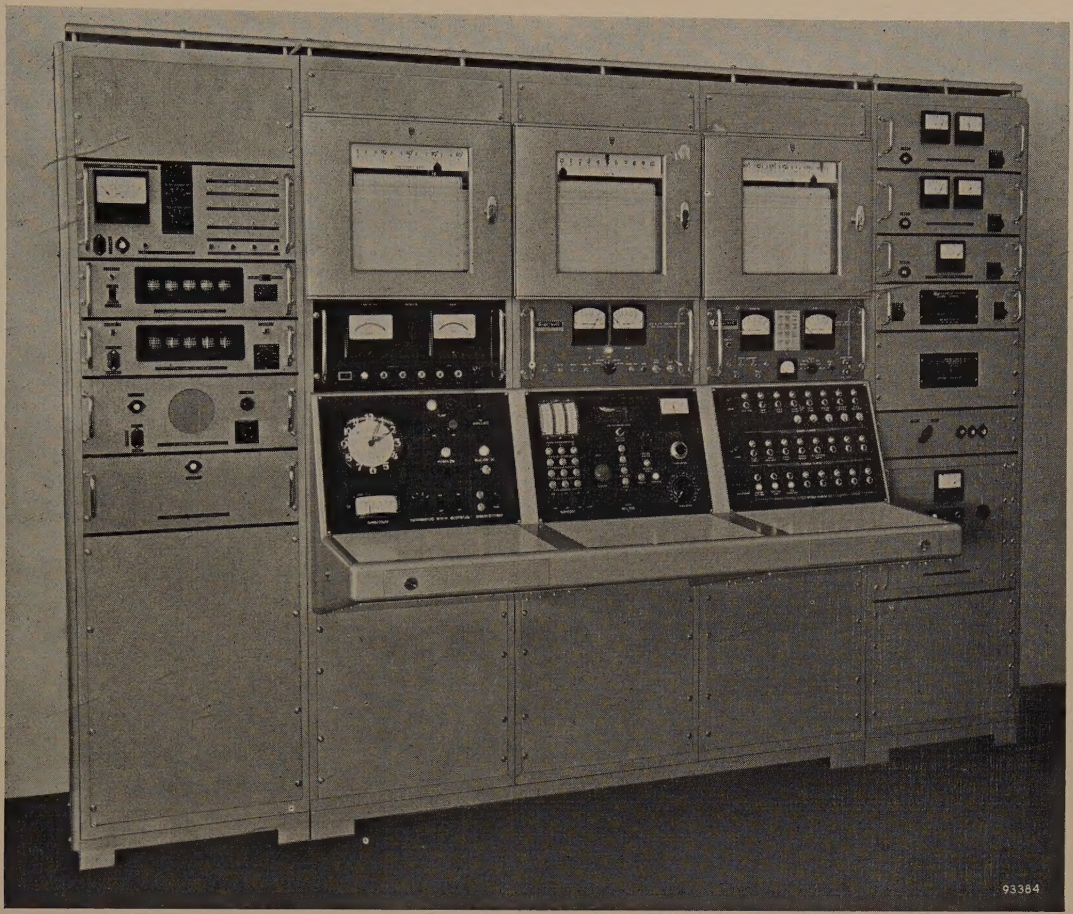

Fig. 3. Console carrying the monitoring control, and safety equipment. Left rack, from above: gamma indicator, pulse counter, pre-set time unit, loudspeaker unit, unit for temperature measurements. The rack on the right contains, among other things, the stabilized voltage sources. For the central section (three racks), see fig. 7.

system for operating the servomotors and the safety mechanism. A closer view of the relay system is given in *fig. 5*.

Neutron flux measuring channels

For measuring and automatically controlling the neutron flux, and also for safeguarding against the consequences of too high flux, it would in principle be enough to use one and the same detector, connected with an amplifier whose output voltage is a measure of the neutron flux. In actual practice, however, no less than five detectors are used, each with its own measuring channel. The reasons for this appear from the following considerations.

a) For *recording* purposes, a *logarithmic* scale is required, because the neutron flux from the initial state to that of maximum power increases by a factor of 10^8 to 10^9. Logarithmic flux measurement is also needed for determining the reactor period. This calls for complicated electronic equipment, capable of meeting high demands as to sensitivity and stability.

b) For *control* purposes, a *linear* measuring instrument is to be preferred. Provided the instrument has sufficient measuring ranges, it can also serve for accurately measuring the neutron flux (the accuracy, of course, would be far less with a meter having a single range covering many decades).

c) The *safety devices* must react not only when the neutron flux is too high, the period too short, the temperature excessive, etc., but also in the event of any fault whatsoever in the safety system itself. Reliability demands therefore a system as simple and robust as possible, and for this reason it cannot well be combined with the other channels. To increase the margin of safety, the safety channel is duplicated.

d) At very *low neutron fluxes* (less than 10^{-5} of the maximum flux) a detector of the kind used for normal flux would deliver too weak a current to be accurately measured. Nevertheless, accurate measurement is still necessary, if only because even at low fluxes the reactor period

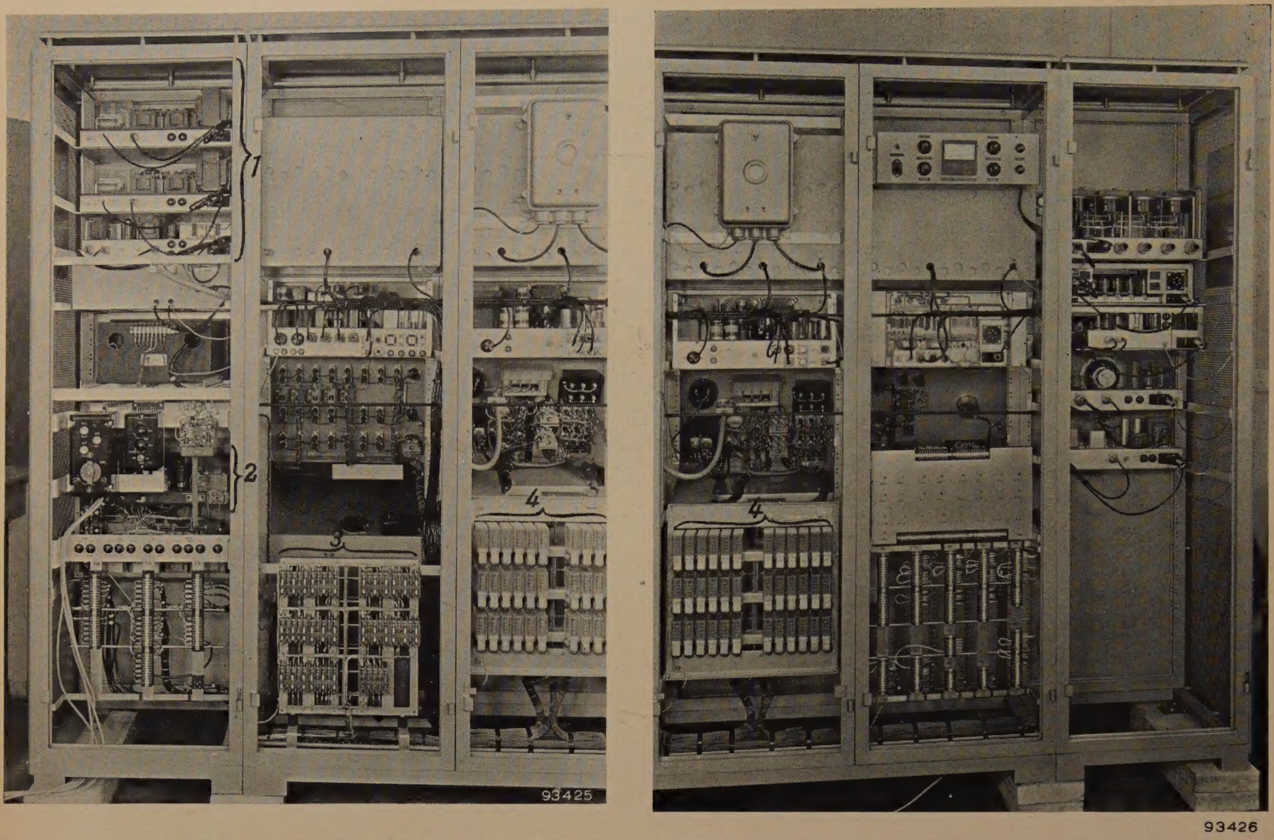

Fig. 4. Rear view of console. *1* three stabilized D.C. power supplies. *2* A.C. voltage stabilizer. *3* and *4* relay banks for servomotors and safety channels (see fig. 5).

must not be too short and must be constantly monitored. Hence the inclusion of a separate channel with different types of detector and amplifier for the measurement of low fluxes.

These considerations led to the following five channels for neutron flux measurement:

1) Channel for low flux, with logarithmic meter, recording apparatus and period meter.
2) Channel for high flux, with logarithmic meter, recording apparatus and period meter.
3) Channel for high flux, with linear meter and recording apparatus; also used for automatic control.
4) and 5) Two identical safety channels, designed with the emphasis on reliability, and having "fail-safe" features.

We shall now discuss the channels in the above order, after which we shall deal with temperature measurement, the position indication of the control and safety rods, gamma-ray measurement and the automatic control of the reactor.

Measuring channel for low neutron flux

The detector for low neutron flux is a so-called fission chamber (of American manufacture), which is a type of counter tube whose inside wall is lined with a fissionable material, in this case uranium. Fission of a uranium nucleus by a neutron results in two fast oppositely-moving fragments, one of which is almost certain to pass through the gas of the counter tube, producing ionization. (Of the

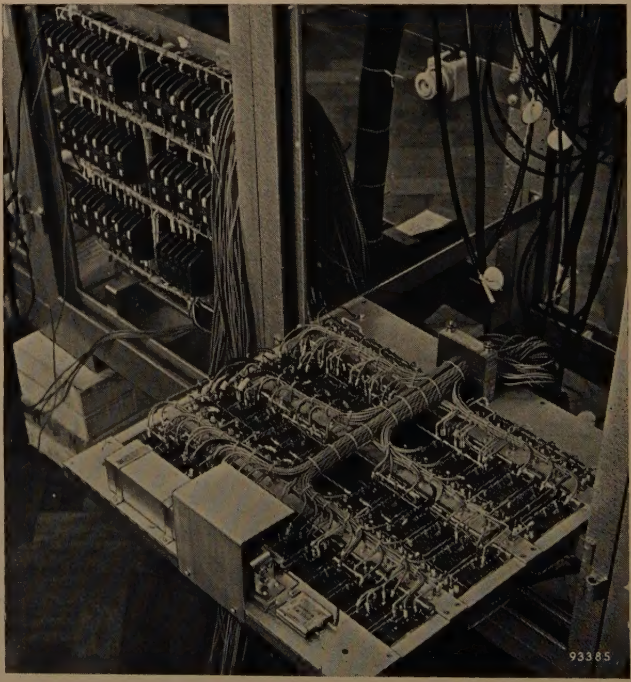

Fig. 5. Relay banks for servomotors and safety channels, one of the relay panels having been lowered for inspection.

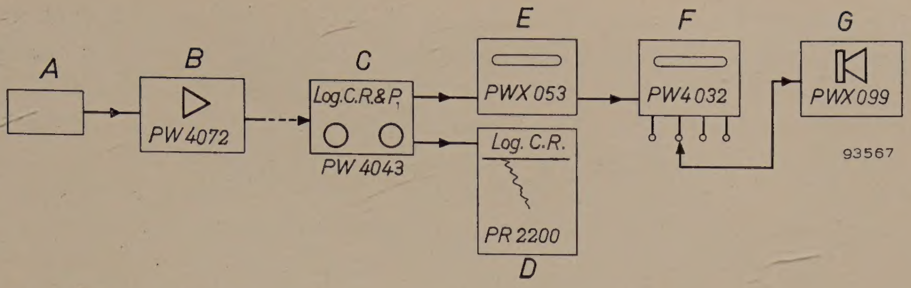

Fig. 6. Block diagram of measuring channel for low neutron flux. *A* fission chamber, *B* pulse amplifier, *C* logarithmic count-rate and period meter, *D* automatic recording potentiometer, *E* pre-set time unit, *F* pulse counter, *G* loudspeaker unit.

92 electrons surrounding the nucleus of a uranium atom, about 40 are stripped off after nuclear fission; thus the fission fragments are ions, each carrying some 20 positive elementary charges.) Consequently, almost every nuclear fission at the wall of the counter tube produces a current pulse.

The detector (*A* in *fig. 6*) is mounted in or near the reactor core and is connected to a linear pulse amplifier *B*, in which the current pulses are converted into voltage pulses and amplified 30 000 times. The amplifier is set up as close as practicable to the detector in order to minimize the capacitance of the connecting cable.

The output pulses, having an amplitude of a few volts, are fed to the logarithmic count-rate and period meter *C* ("log. C.R. & P."). Here they are separated by a discriminator ("Schmitt trigger") from the much smaller background pulses (caused by alpha particles produced in the counter by the radioactive disintegration of certain fission products) and then shaped into pulses of standardized amplitude and width. From these standard pulses a direct voltage V_1 is derived which is proportional to the logarithm of the number of pulses per second, and hence to log. neutron flux N. (Methods of obtaining this logarithmic relation will be discussed

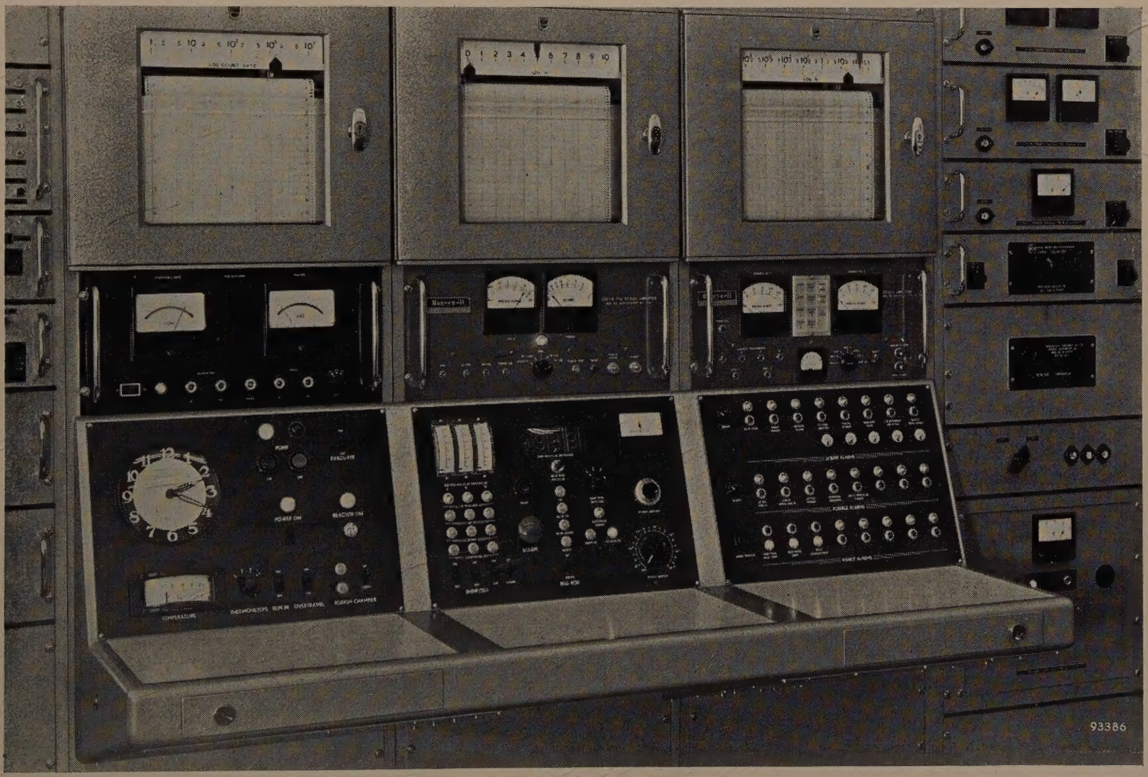

Fig. 7. Central section of console (cf. fig. 3). The three recorders above (from left to right) record respectively low neutron flux on a logarithmic scale ("log. C.R."), high neutron flux on a linear scale ("lin. N") and high neutron flux on a logarithmic scale ("log. N"). Below the recorders are mounted the associated flux, period and power meters.

Control panels: temperature meter below clock; the middle panel contains the position indicators for the safety and control rods and the "Power Demand" knob, and the right panel the pilot lamps.

in Part II.) The voltage V_1 is indicated on a voltmeter as well as recorded by an automatic potentiometer (*fig.* 7), both having a logarithmic scale from 1 to 10^4 pulses per second. From V_1 a differentiating amplifier derives a voltage V_2 which is proportional to

$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}t},$$

that is to the relative change in the neutron flux per second. V_2 is thus inversely proportional to the period T (the time in which the flux increases by a factor e) and it is made to deflect the needle of a meter on which T can be read directly in seconds. The unit containing the logarithmic counting-rate and period meter is shown separately in *fig. 8*.

The actual counting is performed by five decimal counter tubes, type E1T [3]), mounted in unit PW 4032 (fig. 3). Fluorescent spots on the walls of these tubes together indicate a five-digit number which corresponds to the number of pulses counted in a given time. Apart from the direct indication in decimal digits, an advantage of this apparatus is its very rapid counting rate (resolution time 0.5 μsec) [4]).

The counting period can be pre-set with unit PW X053 (*fig. 9*). This contains two gate circuits, which can be simultaneously opened by means of a push-button. The one gate then passes the pulses to be counted to the counter circuit PW 4032; via the other gate, auxiliary pulses from the mains voltage (50 per second) are passed to a similar counting device in unit PW X053. As soon as a pre-set number of auxiliary pulses is reached, the second counting system closes both gates. The number of fission pulses counted in the time selected can now be read on the counter tubes of the first gate. The counting time, determined by the number of auxiliary pulses, can be adjusted in steps from 5 to 2000 sec (knob on the right in fig. 9). In this way very small values of neutron flux can still be accurately measured.

Finally, there is the loudspeaker unit PW X099 (fig. 3 and fig. 6). With this it is possible to make audible either all pulses counted by unit PW 4032 or only each tenth, hundredth or thousandth pulse. During start-up of the reactor, when the neutron flux is still low, the operator must watch several meters at the same time, for which reason an audible signal has proved very useful. A change in the average pulse rate can be heard immediately; a too rapidly increasing pulse rate means too short a period, indicating the necessity for prompt action.

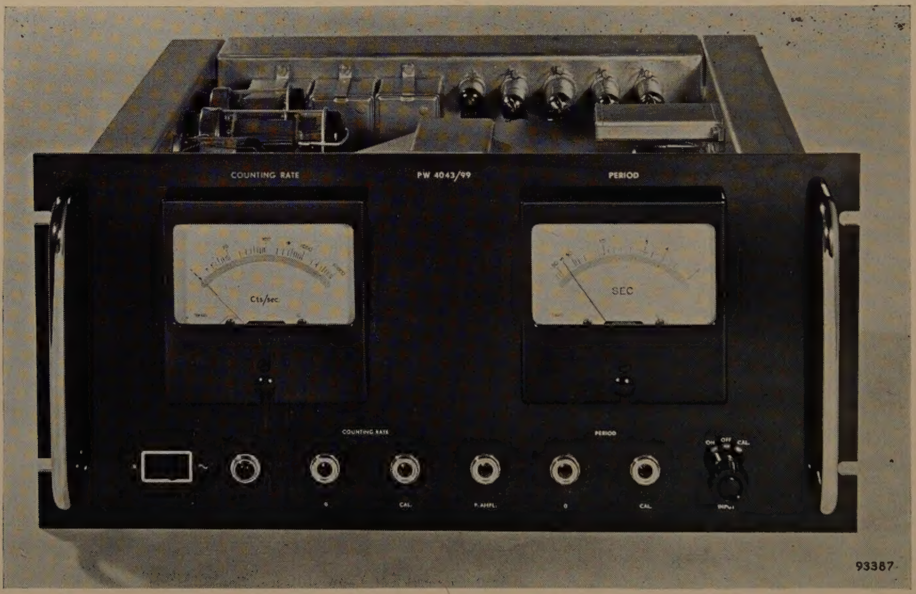

Fig. 8. Logarithmic count-rate and period meter PW 4043 for low neutron flux. The meter on the left indicates the number of pulses per second (scale 1 to 10^4), the meter on the right indicates the reactor period in seconds (scale from —30 via ∞ to 3 seconds; cf. fig. 10).

The operating personnel find the audible signal so valuable that they also make use of the low-flux channel even at high neutron-flux levels (the low-flux channel being the only one which provides an audible signal). For this purpose the fission chamber is raised sufficiently above the reactor to reduce the pulse rate to a usable value.

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[3]) A. J. W. M. van Overbeek, J. L. H. Jonker and K. Rodenhuis, Philips tech. Rev. **14**, 313, 1952/53.

[4]) E. J. van Barneveld, Philips tech. Rev. **16**, 360, 1954/55.

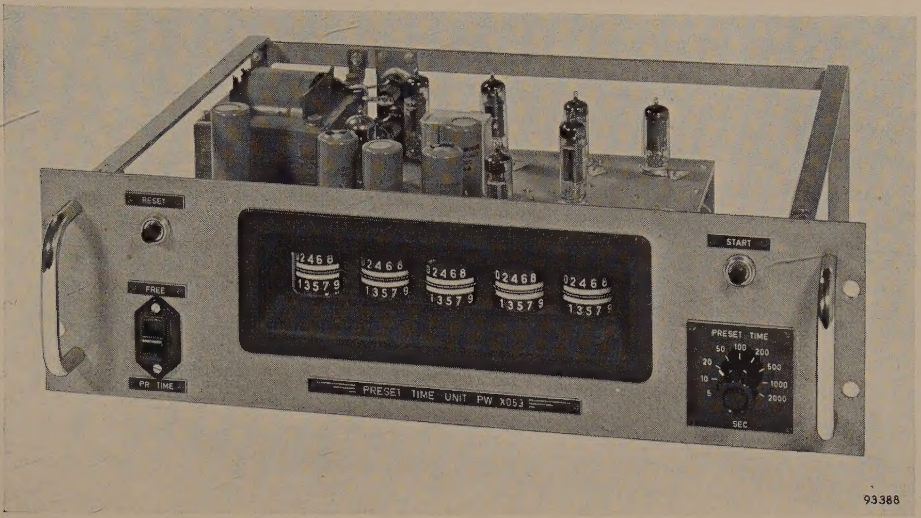

Fig. 9. Pre-set time unit PW X053 with five decade counter tubes type E1T. When the start button (top right) is pressed, this circuit begins to count auxiliary timing pulses (50 per second) and at the same time unit PW 4032 begins to count the pulses from the fission-chamber counter. As soon as the pre-set number of timing pulses has been reached (corresponding to a time of 5 to 2000 seconds, adjusted by the switch, bottom right), both counters stop automatically and the number of fission-chamber pulses counted can be read on unit PW 4032. If the switch, bottom left, is put in the "free" position, the PW 4032 unit goes on counting. The push-button, top left, serves for setting the counter PW X053 to zero.

Logarithmic measuring channel for high neutron flux

In the case of high flux levels, separate pulses are not counted as in the measurement of low neutron flux, but the average direct current of an ionization chamber is measured. To be more exact, what is measured is the difference current of the two parts of a differential (or "compensated") ionization chamber (of American manufacture). Only one of these parts is sensitive to neutrons, its wall being lined with boron carbide, but both are sensitive to the same degree to gamma radiation, which can be particularly intense in the reactor core. By taking the difference current, the effect of the gamma radiation is eliminated; the measured current is thus proportional to the neutron flux.

The difference current (50 μA at the nominal power) is fed to a logarithmic neutron flux meter (annex period meter) PW X081. As will be explained in detail in Part II, the grid-cathode space of an electron tube in a special circuit functions in this meter as a logarithmic element. In this way a voltage is obtained which is almost exactly proportional to the logarithm of the difference current over a very wide range (6 to 7 decades). After amplification a voltage is produced which is indicated on a meter and also recorded ("log. N recorder"). The scale, calibrated in %, runs from 10^{-4} % to 300 %, corresponding to difference currents from 5×10^{-11} A to 1.5×10^{-4} A. The first decade (10^{-4} to 10^{-3} %) of this instrument coincides with the last decade (10^3 to 10^4 pulses per second) of the meter for low neutron flux.

As in the case of the channel for low flux, a differentiating amplifier delivers a voltage which is inversely proportional to the period T; the latter can be read directly from a meter in seconds (*fig. 10*).

The supply voltages needed for the ionization chambers are a direct voltage of 600 V positive with respect to earth, and one of max. 350 V negative with respect to earth, the latter being adjustable in steps of approximately 35 V. Both voltages are stabilized and are taken from the power supply units PW X023.

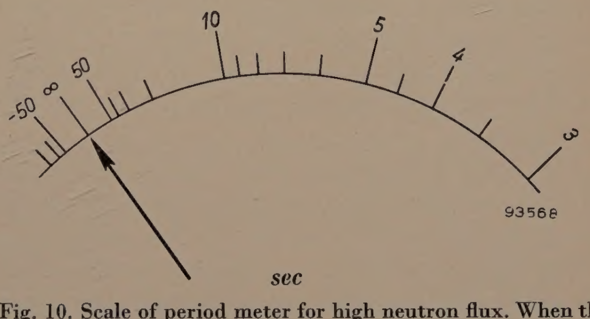

Fig. 10. Scale of period meter for high neutron flux. When the reactor is operating in the stationary state, the meter needle shows infinity. A positive deflection indicates increasing power, a negative deflection decreasing power. Audible and visible alarm signals are given if T drops below 10 sec; "fast scram" results automatically if T drops below 3 sec.

Linear measuring channel for high neutron flux

Owing to the wide range they cover, the logarithmic channels are especially suitable for use when putting the reactor into operation and for obtaining a rough impression of the value of the neutron flux at a given moment; they are also needed for measuring the reactor period. A linear channel, however, which in this reactor has 18 measuring ranges, is used for accurate measurement, and also as the basis of the automatic control.

The neutron detector is a compensated ionization chamber of the same type as that in the logarithmic channel for high neutron flux. The current from this detector is passed through a high resistance. To cover the range of 6½ decades, 18 such resistors with values rising in the ratio 1, 2, 5, 10, ... (to a maximum of 10^9 ohms) are mounted together with a high-insulation switch in a magnetically and electrically screening housing. The switch can be operated from the control desk.

The voltage across the resistor is measured with the aid of a vibrating capacitor [5]) and an amplifier (unit PR 7500) combined with an automatic recording potentiometer (type PR 2201). The linear scale of this "lin. *N* recorder" runs from zero to 10.0 (fig. 7).

Safety channel

As remarked, the safety system of the reactor is kept as far as possible separate from the other measuring apparatus for the sake of maximum reliability, the requirement being that the safety rods should fall not only when something is amiss in the reactor but also if any fault whatsoever should develop in the safety installation itself. Since inconvenience and loss of time are caused every time the rods fall, measures must be taken on the other hand to reduce to a minimum the chance of the rods being dropped without any real necessity. In the design of the safety installation, therefore, the aim must be to use as few components as possible, and these must be robust and of very high quality. Furthermore, the wiring system needs careful consideration.

The link between a very robust ionization chamber and the relay contacts through which the energizing current flows to the electromagnets from which the safety rods are suspended, is formed by the *safety amplifier*. This will be described in detail in Part II. In the event of too high neutron flux or internal disturbances, this device stops the reactor in the shortest possible time ("fast scram"). The same happens if the reactor period is too short: a relay in the "log. *N* and period" unit PW X081 interrupts the magnet currents if *T* drops to less than 3 seconds. This is done via a relay contact in the D.C. circuit of the electromagnets and also, as an extra precaution, via a relay contact on the A.C. side of the rectifier which supplies the magnet current.

There are further contacts incorporated on the A.C. side, their purpose also being to stop the reactor if certain troubles develop. Because of the energy accumulated in the rectifier smoothing circuit, the opening of an A.C. contact causes the magnet current to drop less rapidly to zero than the opening of a D.C. contact. This "slow scram", as it is called, is sufficient for certain less urgent cases (see *Table I*) and does not complicate the fast-scram line.

Thirdly, there are several relays which serve not to stop the reactor but only to set off a visible and sometimes also an audible alarm; see *Table II*. (In Delft the number of cases calling for "slow scram" and alarm signals will be extended.)

On the right-hand operating panel (fig. 7) the "safe" and "unsafe" signals are given by the burning of green and red pilot lamps respectively. This duplicated signalling system is again an extra safety precaution: if a red pilot lamp should fail to light up, the fact that the associated green lamp is not burning is a warning that something is wrong. The top row of pilot lamps relates to the "scram alarms", the second row to cases 1) to 5) in Table II (in these cases a buzzer signal is sounded at the same time). In cases 6), 7) and 8) the only indication is given by the pilot lamps in the bottom row.

Table I. Less urgent cases in which the reactor is stopped ("slow scrams").

Case	Shut-down device
1) Shut-down by hand	Push-button on central control panel (fig. 7) and at several points around the reactor.
2) Too low or no voltage on the compensated ionization chambers	Relay in each stabilized voltage source.
3) Excessive gamma radiation	Four meter relays in the gamma indicator (see Part II).
4) Reading on "log. C.R. meter": *a*) < 2 (due to fault in meter or because fission chamber is too high)	Slide contacts and relay in "log. C.R. recorder".
b) > 10^4, while reading on "log. *N*" < 2×10^{-4} % (due to fault in "log. *N* meter", or because fission chamber is too low)	Slide contacts and relay in "log. C.R. recorder" and in "log. *N* recorder".
5) Reading on "log. *N*" > 150 % (neutron flux too high)	Slide contacts and relay in "log. *N* recorder".
6) One or more of the safety rods not attached to their electromagnets	Contacts on the magnets, which are closed only if rods are properly attached.

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[5]) See, for example, Philips tech. Rev. 7, 28, 1942.

Table II. Cases in which the reactor is not stopped, but an audible and visible alarm signal is given (cases 1 to 5) or only a visible signal (cases 6, 7 and 8).

Case	Device
1) $T < 10$ sec (pre-warning before period scram at $T < 3$ sec)	Relay in the period amplifier (see Part II).
2) Unusually large deviation of servomechanism from equilibrium position	Relay in control channel.
3) Power exceeds 110 % of nominal value (pre-warning before high-flux scram at 150 %)	As (5) in Table I.
4) Shim rods need adjustment because control rod has moved beyond its range	Contact in the path of control rod.
5) Defects in power supply for servomotors	Relay in control channel.
6) Water temperature near ion exchanger too high	Thermo-switch in ion exchanger.
7) Water temperature in the tank too high	Thermo-switch in the tank.
8) Conductivity of water too high	Relay in a bridge that measures the water conductivity.

Other measurements

Temperature measurements

Although there could scarcely be any appreciable rise in the temperature of such a large volume of water (50 m^3) at the low maximum power of 10 kW at which the reactor operated at the Exhibition, the temperature was nevertheless measured at several points. This measurement will be of more importance when the power is raised to 100 kW, since the effective multiplication factor k in a reactor is closely dependent on the temperature (having a negative temperature coefficient).

The measurement is carried out by means of resistance thermometers, consisting of a platinum wire (100 ohms) in a sheath of stainless steel which is soldered water-tight to the lead sheath of the connecting cable. The platinum resistance element forms an arm of a bridge circuit, the output voltage of which, after amplification, deflects the needle of a meter calibrated in °C. This meter can be seen below the clock in fig. 7. At the right of the meter is a knob for switching over to different thermometer elements; at the left is unit PR X010 with the bridge circuit and amplifier.

Rod-position indicators

It is desirable to be able to read on the control desk the position of the control rod and safety rods. This will also be of use in experiments concerning the sensitivity of the control process at different positions of the rods.

The position indication is effected by the mechanical coupling of each rod to the slide contact of an accurate helical potentiometer ("Helipot") which is connected to a source of constant voltage. The voltage between the slide contact and a point of reference (corresponding to the lowest position of the rod) is measured with a voltmeter. The three voltmeters that indicate the positions of the safety rods can be seen top left on the middle control desk in fig. 7.

These meters do not give an accurate enough reading for all cases, and certainly not for the control rod. For exact position indication, therefore, an electronic voltmeter with digital display is used (product of Non-Linear Systems Inc.) whose reading is determined by separate potentiometers coupled to the control rod and to the safety rods. This meter, which is to be seen immediately on the right of the three voltmeters in fig. 7, gives a direct reading to four figures. As a rule the meter is employed for continuously indicating the position of the control rod, but by means of a push-button and a switch it can also indicate the position of each of the safety rods and that of the fission chamber for low neutron flux.

Gamma indicator

A special ionization chamber with electrometer tube is mounted near the ion exchanger and two others at points above the surface of the water. The dose rate of the gamma radiation at each position produces a reading on a logarithmically graduated meter; the latter can be seen on the left in fig. 3. Further particulars will be given in Part II.

Automatic control of the reactor

The design of the nuclear reactor here discussed provides for the automatic control of the neutron flux (and hence of the power output) once this has been set to the required value by hand. The reactor is not started up automatically, as some high-power reactors are, but by the following procedure.

First of all, the safety rods are raised "manually", that is to say with the hand switch that controls the servomotors. While this is being done, the neutron flux and period meters must be watched to see that the rods are not raised too quickly. Only when they have reached a position where k is almost 1 can the operator begin to raise, very carefully, the control rod. Initially, only the meter for low neutron flux gives a reading, as a result of the activity of the artificial neutron source, which supplies the first neutrons. As the control rod gradually rises, fewer neutrons are absorbed and the low-flux period meter now gives a reading.

With the raising of the control rod the neutron multiplication factor k, which initially was only about 0.9, gradually increases until it is finally greater than 1. The chain reaction in the uranium now sets in, and at the same time the neutron flux spontaneously rises, i.e. without the control rod being moved any further. This produces a reading on the meter for high neutron flux. By fractional displacements of the control rod the rate at which the flux increases can be slightly altered, to keep it down to, say, 5% per second (period longer than 20 seconds).

In this way the flux can be brought to the required value in about 10 minutes. Once this is reached, the control rod is lowered to a position where k is exactly 1 (the period meter then shows infinity and the counting-rate meter gives a constant reading). In practice it is not possible to maintain this state exactly, but it can be very closely approached, so that slight adjustments of the control rod are needed only after long intervals. (However, the instruments would have to be kept under constant observation.)

This monotonous work can better be entrusted to an automatic control mechanism, which functions as follows.

The recording pen of the instrument which registers the neutron flux on a linear scale is mechanically coupled with the slide contact of a potentiometer. This forms a bridge circuit with a second potentiometer, which can be manually adjusted to accord with the power required. The bridge output voltage ε is thus a measure of the difference between the prevailing neutron flux and that corresponding to the required power. The principle of the control is that the voltage ε is fed to an amplifier, which produces an alternating voltage proportional to ε; this alternating voltage actuates one phase of a two-phase servomotor, which causes the control rod to move in the appropriate direction.

In reality the circuit of the amplifier designed for this purpose (type PR X083) is rather more complicated. Apart from a negative feedback which is linearly dependent on the position of the control rod, the amplifier contains a differentiating and an integrating element. The relation between the shift x of the control rod, the potential difference ε and the time t is accordingly:

$$x = A \left[\varepsilon + \tau_{\mathrm{d}} \frac{\mathrm{d}\varepsilon}{\mathrm{d}t} + \frac{1}{\tau_{\mathrm{i}}} \int \varepsilon \mathrm{d}t \right],$$

in which the factor A and the time constants τ_{d} and τ_{i} are variable quantities. The differential term makes it possible for the final state to be reached more rapidly without the risk of instability, and the integral term allows the required state to be reached exactly instead of just approximately [6].

The second potentiometer mentioned above, being another "Helipot" wire potentiometer, enables the required power to be adjusted with considerable precision. Ten revolutions of the knob are needed to move the slide contact over the whole resistance wire. The knob (marked "Power Demand") is on the right of the central control desk (fig. 7).

Since they differ in certain respects from the instruments commonly used for the same purpose, the logarithmic neutron flux and period meter for high flux, the gamma indicator and the safety amplifier will be dealt with more in detail in Part II.

Appendix: Fuel consumption and reaction products of a nuclear reactor

The fact that a nuclear reactor consumes extremely little "fuel" appears from the figures given below.

One gram-atom of U^{235}, i.e. 235 grams, contains 6.02×10^{23} atoms (Avogadro's number). Therefore one gram U^{235} contains $6.02 \times 10^{23}/235 = 2.56 \times 10^{21}$ U^{235} nuclei, and upon fission these yield $2.56 \times 10^{21} \times 3.2 \times 10^{-11} = 8.2 \times 10^{10}$ joules $= 8.2 \times 10^{7}/60^{2}$ kWh $= 2.28 \times 10^{4}$ kWh. The generation of, say, 100 kW (in the form of heat) over a period of 24 hours therefore requires only $2400/(2.28 \times 10^{4}) \approx 0.1$ gram U^{235}. To generate the same amount of heat by complete combustion of coal, 300 kg of coal would be needed.

Of the substances produced in a nuclear reactor, the first to be mentioned are the *fission products*, i.e. the fragments into which U^{235} nuclei have split and whatever may come forth from these fragments. A U^{235} nucleus can split into two parts in more than 45 ways, over 90 different fission fragments having been identified (including the elements 43 and 61 — technetium and promethium respectively — which have never been found in nature). Owing to a surplus of neutrons, most fission fragments are not stable. Some of these neutrons are transformed in the nucleus into protons, during which process the nucleus emits an electron (beta emission) and possibly a gamma quantum, while others are liberated, after a beta emission, as "delayed" neutrons (see above). Often several beta emissions are needed before a radioactive fission fragment can reach nuclear stability. Two examples of such a disintegration in four stages accompanied by beta emission are:

$${}_{54}\mathrm{Xe}^{140} \xrightarrow[\beta]{16\mathrm{s}} {}_{55}\mathrm{Cs}^{140} \xrightarrow[\beta]{66\mathrm{s}} {}_{56}\mathrm{Ba}^{140} \xrightarrow[\beta]{12.8\,\mathrm{d}} {}_{57}\mathrm{La}^{140} \xrightarrow[\beta]{40\mathrm{h}} {}_{58}\mathrm{Ce}^{140} \text{ (stable)},$$

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[6] See, for example, H. J. Roosdorp, On the regulation of industrial processes, Philips tech. Rev. **12**, 221-227, 1950/51.

$$ {}_{36}\mathrm{Kr}^{90} \xrightarrow[\beta]{33\mathrm{s}} {}_{37}\mathrm{Rb}^{90} \xrightarrow[\beta]{2.7\ \mathrm{min}} {}_{38}\mathrm{Sr}^{90} \xrightarrow[\beta]{19.9\ \mathrm{y}} {}_{39}\mathrm{Y}^{90} \xrightarrow[\beta]{61\mathrm{h}} {}_{40}\mathrm{Zr}^{90}\ \text{(stable).} $$

An example of a case in which a delayed neutron is liberated is:

$$ {}_{35}\mathrm{Br}^{87} \xrightarrow[\beta]{55.6\ \mathrm{s}} {}_{36}\mathrm{Kr}^{87} \xrightarrow[\mathrm{n}]{0} {}_{36}\mathrm{Kr}^{86}\ \text{(stable).} $$

The half-life of these substances is mentioned in the examples. In some cases the half-life is so long (e.g. 19.9 years for Sr^{90}, see the second example) that the question of where the fission products are to be disposed of requires careful consideration.

Another series of transformations taking place in a uranium reactor begins with the absorption of a neutron of 6.5 eV by a U^{238} nucleus (resonance). This gives rise to ${}_{92}\mathrm{U}^{239}$, which, with two beta emissions, transforms into plutonium (${}_{94}\mathrm{Pu}^{239}$), with neptunium (${}_{93}\mathrm{Np}^{239}$) as intermediate product. Plutonium can be separated by a chemical process from the mixtures of reaction products, and put to further use as nuclear fuel, Pu^{239} nuclei being fissionable by neutron capture.

Finally, it may be noted that, because of the low power of the reactor shown at the Exhibition "Het Atoom", the fission products constituted no problem and there was no significant production of plutonium.

Summary. The monitoring, control and safety equipment described relates to the experimental nuclear reactor (of American manufacture) which was exhibited in operation at the 1957 exhibition "Het Atoom" in Amsterdam, and which is shortly to be transferred to Delft. A brief description is first given of the operation of a nuclear reactor. The equipment contains the following channels for the measurement of the neutron flux: a low-flux channel (with logarithmic scale), two high-flux channels (one with logarithmic and one with linear scale) and two identical independent safety channels. The two logarithmic channels each contain a period meter, which indicates the "period" (time constant) of the nuclear reactor directly in seconds. The installation includes devices for measuring the temperature of the water and for indicating the position of the control and safety rods, a gamma-ray indicator and an automatic control system. An appendix gives a few details concerning the fuel consumption and the reaction products of a nuclear reactor.

A RADAR SONDE SYSTEM FOR UPPER AIR MEASUREMENTS

621.396.969: 551.508.8

The measurement of upper air conditions is an important branch of meteorology because information is required for research, for weather forecasting and for aircraft operation. Although the first soundings were made in the 18th century, using kites and manned balloons, the systematic measurement of air conditions at great heights has become possible only since the development of radio and radar. The development of radio and radar sonde equipment is therefore one of the most significant advances in meteorological instrumentation.

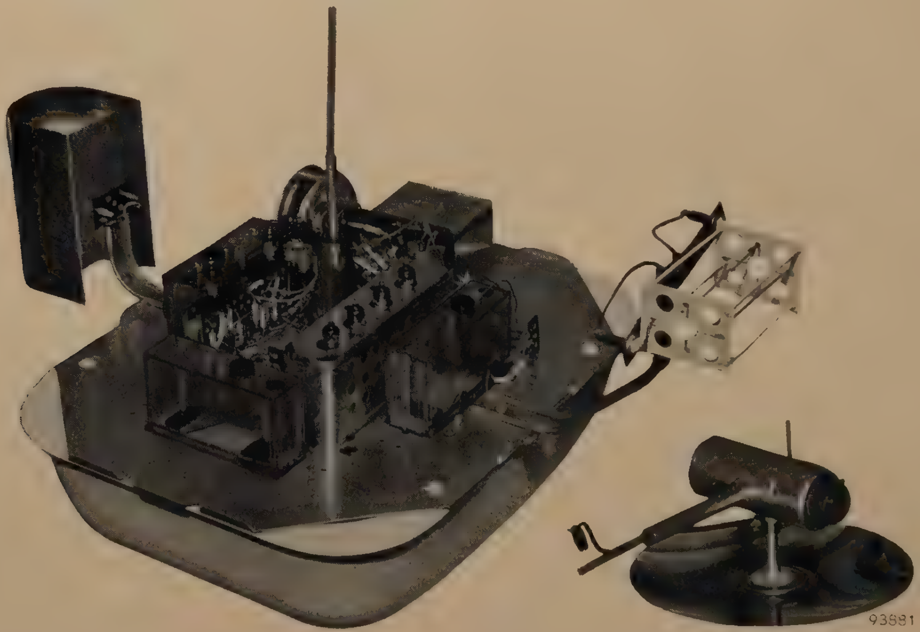

Fig. 1. Airborne unit of the radar sonde (cover removed). The humidity and temperature measuring elements are carried on external arms; the main part of the unit is enclosed in a thermally insulating case. The aerial, receiver, telemetering circuit, switch, barometer and batteries are seen mounted on the chassis plate. The 10 cm wave transmitter and aerial assembly, which are mounted underneath the chassis plate, are shown separately on the right-hand side of the photograph.

The airborne unit is suspended from a hydrogen-filled balloon which is approximately 2 m in diameter at the ground and lifts the unit at 360 m per minute (1200 ft/min). A parachute is inserted in the suspension to allow a gentle descent after the balloon has burst (at a height greater than 80 000 feet).

In the following note, a short description will be given of a radar sonde system which has been developed by the Mullard Research Laboratories, Salfords (England), in conjunction with the Royal Radar Establishment, Malvern, for measurements of wind speed, wind direction, temperature, pressure and humidity at heights up to at least 24 km (80 000 ft) [1]). The equipment is automatic in operation and provides continuous records at a ground station of the wind vector as a function of height. Temperature, pressure and humidity are measured and recorded at the ground station at approximately 100 m intervals of the height of the sonde.

For each sounding, an airborne unit (which in a large percentage of soundings is not recovered) is carried into the upper atmosphere by a free, hydrogen-filled balloon. This unit (*fig. 1*) contains a small combined transmitter and receiver with auxiliary equipment and instruments for measuring temperature, pressure and humidity. The transmitter allows the telemetering of these data during the whole ascent, until the bursting of the balloon, which may occur after it has reached a height greater than 80 000 feet and travelled a distance of over 100

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[1]) See also: F. E. Jones, J. E. N. Hooper and N. L. Alder, The radar sonde system for the measurement of upper wind and air data, Proc. Instn. El. Engrs. **98**, II, 461-469, 1951.
A. L. Maidens, Sounding the upper atmosphere, Discovery **18**, 156-160, 1957 (No. 4).

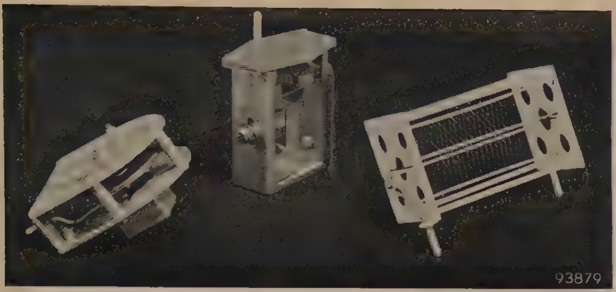


Fig. 2. *Left*: the aneroid barometer; *right*: the fine-wire resistance thermometer; *centre*: the skin hygrometer. The aneroid and hygrometer are conventional elements, but the thermometer is a considerable improvement over earlier types. It is constructed with fine, coiled-coil, tungsten wire, has a very short time constant and a very small radiation error at high altitude.

miles from the release point. Tracking the flight of the balloon by radar at the ground station provides the data necessary for determining the wind vector and height at each moment. Conventional radar methods, which depend on a pulse signal transmitted by the ground station being *reflected* by the target, would involve a very high transmitting power in order to enable the balloon to be tracked during its whole flight. Therefore in this radar sonde a system known as "secondary radar" has been employed. The airborne transmitter is made to send a pulse (or in fact 2 pulses, see later) every time the airborne receiver picks up a pulse signal transmitted by the ground station. The time delay measured at the ground station between the departure of the "interrogating pulse" and the arrival of the "responding pulse" is a direct measure of the range of the balloon; the azimuth and elevation angles of the transmitting aerial, which is automatically kept aligned on the balloon, convey the information concerning its direction.

The interrogating signal has a frequency of 152.5 Mc/s and is transmitted at a peak power of 50 kW with a pulse repetition rate of 404 pulses per second. The responding signal of the airborne transmitter has a frequency of 2850 Mc/s and is radiated at a peak power of 0.03 kW.

For the sensing of pressure, humidity and temperature, the airborne unit carries an aneroid barometer, a goldbeater's skin hygrometer and a resistance thermometer (*fig. 2*). The changes in these elements under varying atmospheric conditions are converted into voltage variations which, in turn, control an "encoding" circuit. This circuit is triggered by each of the interrogating pulses, derived from the receiver, and generates a pulse of its own with a time delay dependent on the control voltage. The airborne transmitter is operated both by this delayed pulse and by the interrogating pulse and thus transmits back to the ground a pair of pulses for each interrogating pulse, the time delay between the two pulses of a pair representing the reading of the meteorological instrument. The control voltages of the three instruments are brought into operation in sequence by a motor-driven switch, so that each instrument reading is encoded once every 17 seconds.

The airborne centimetric transmitter contains a triode transmitting valve, controlled by a blocking-oscillator modulator and mounted in a coaxial cavity designed to facilitate large-scale production. The transmitter aerial is an unipole with counterpoise (fig. 1). The power supply of the sonde comprises three primary cells and a vibrator.

The ground equipment is divisible functionally and physically into two groups. The *radar* group is concerned with the interrogation of the airborne unit, reception of the return signal and determination of the basic positional data (azimuth angle, elevation angle and slant range of the balloon as a function of time). The *computer* group continuously translates the positional data into wind speed and direction, decodes the telemetering signal and records all the results in graphical and printed form.

The radar equipment is illustrated in *figs 3* and *4*. The transmitting aerial (a Yagi array) and the

Fig. 3. The Yagi array transmitting the 50 kW interrogating pulses of 2 m waves is mounted on a common pedestal with the receiving aerial, a 5 ft diameter parabolic reflector with nutating dipole. They are automatically kept aligned on the balloon.

receiving aerial (a parabolic reflector) are mounted on a common pedestal driven by a motor servosystem. The receiving aerial is fitted with a nutating dipole which produces a conical scan of the narrow aerial beam and superimposes a modulation on the received signal when the aerial is incorrectly aligned. This error signal steers the servosystem so as to give accurate automatic following of the balloon in direction. The microwave receiver, which is equipped with automatic gain and frequency control, amplifies the signal from the balloon and delivers it to the automatic ranging system and the telemetering system. The ranging system is of a novel type in which the rotation of a motor-driven, phase-shifting transformer is related to the change in distance of the balloon, so that the speed of rotation is an accurate measure of the radial velocity of the balloon (radial wind component). A rotation of 360° is equivalent to a change in distance of one tenth of a nautical mile. The phase-shifting transformer, therefore, permits fractions of a tenth of a mile to be measured; full tenths of a mile are determined by counting the number of oscillations of a crystal calibrator occurring between transmitted and responding pulse. The calibrator controls the pulse repetition frequency of the transmitter and oscillates with a time period exactly corresponding to one tenth of a nautical mile in radar range. The received signal is monitored and readings of range R, azimuth Θ and elevation E are provided by a display unit (fig. 4). This unit is also fitted with the manual controls for range and aerial position which are used at the beginning of a flight before the equipment is finally switched over to fully automatic operation.

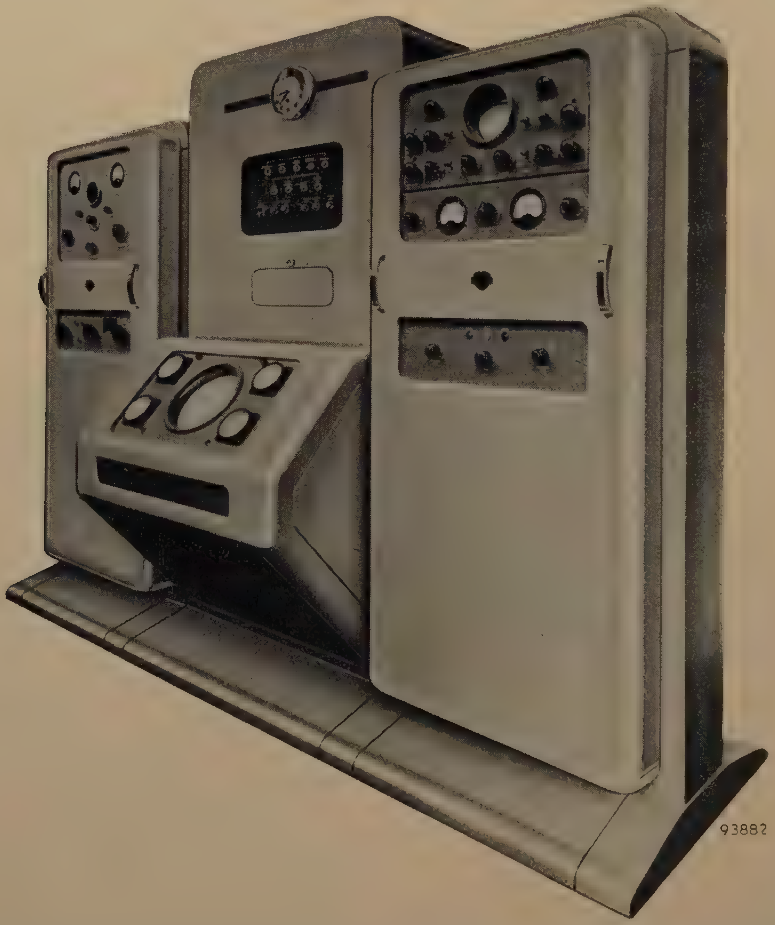


Fig. 4. The radar console. The left-hand unit contains the 50 kW transmitter, the right-hand unit the 10 cm wave receiver and the automatic ranging and aerial-alignment equipment. The centre unit is the display and control system.

The continuous computation of the wind vector (which is parallel to the surface of the earth) is effected from the tangential and radial wind components, given by the equations (in spherical polar coordinates):

$$V_\mathrm{T} = R\,(\mathrm{d}\Theta/\mathrm{d}t)\cos E\,,$$

$$V_\mathrm{R} = (\mathrm{d}R/\mathrm{d}t)\cos E - R(\mathrm{d}E/\mathrm{d}t)\sin E\,.$$

An important feature of these equations is the occurrence of the derivatives of (slant) range R, azimuth Θ and elevation E with respect to time t, i.e. the radial and angular velocities. The auto-ranging and auto-alignment circuits are so designed as to provide signals directly proportional to these velocities. The wind computer which determines the vector resultant of V_T and V_R is illustrated in *fig.* 5. It is an analogue computer employing precision potentiometers for multiplication and magslips (synchros) for trigonometrical computation. The vector amplitude and direction are derived from V_T and V_R in a "triangle-solver" magslip whose rotor shaft assumes a position corresponding at every moment to the wind direction. A 4 ft diameter recording table is directly coupled to this shaft and a recording pen is driven at a constant speed in a radial direction across the table. The pen thus traces out a continuous graph of instantaneous wind direction against time. A voltage proportional to the vector amplitude, i.e. the wind speed, is induced in the magslip rotor coil and is recorded by a conventional recording meter. The height of the balloon, corrected for earth curvature, is computed by similar analogue methods and recorded as a function of time.

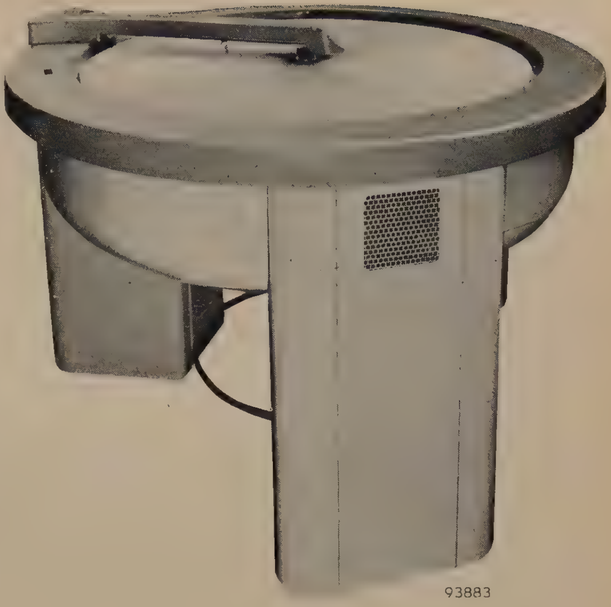


Fig. 5. The wind computer. A magslip turns the rotatable 4 ft diameter table so that at every instant it has a position corresponding to the computed wind direction. A recording pen moving at constant speed along the fixed radial arm traces out a graph of wind direction as a function of time (cf. fig. 7).

The ground telemetering equipment, shown in *fig.* 6, is designed to identify the coded signals from the balloon, to measure accurately the time delay between the ranging and telemetering pulses and to encode the results in a form suitable for operating a standard teleprinter. The time delay is measured by allowing crystal-controlled timing pulses, with a one microsecond separation, to pass through a gating circuit during a period initiated by the ranging pulse and terminated by the telemetering pulse. The total number of timing pulses corresponding to five hundred pairs of signal pulses is counted by an electronic counter and the average delay is transferred to the teleprinter encoder. The figures are printed by the teleprinter in five columns, each of four digits, corresponding to the three meteorological parameters and two reference signals which are also transmitted by the airborne unit. Coding sig-

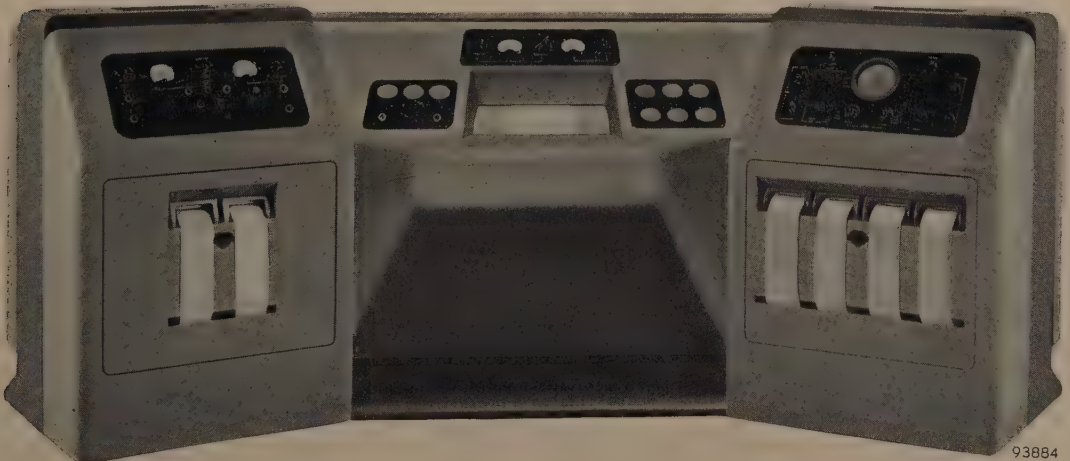


Fig. 6. The telemetering console. The left-hand unit contains wind-speed and height recorders, the right-hand unit encoders and temperature, pressure and humidity recorders and the centre unit a digital computer and teleprinter.

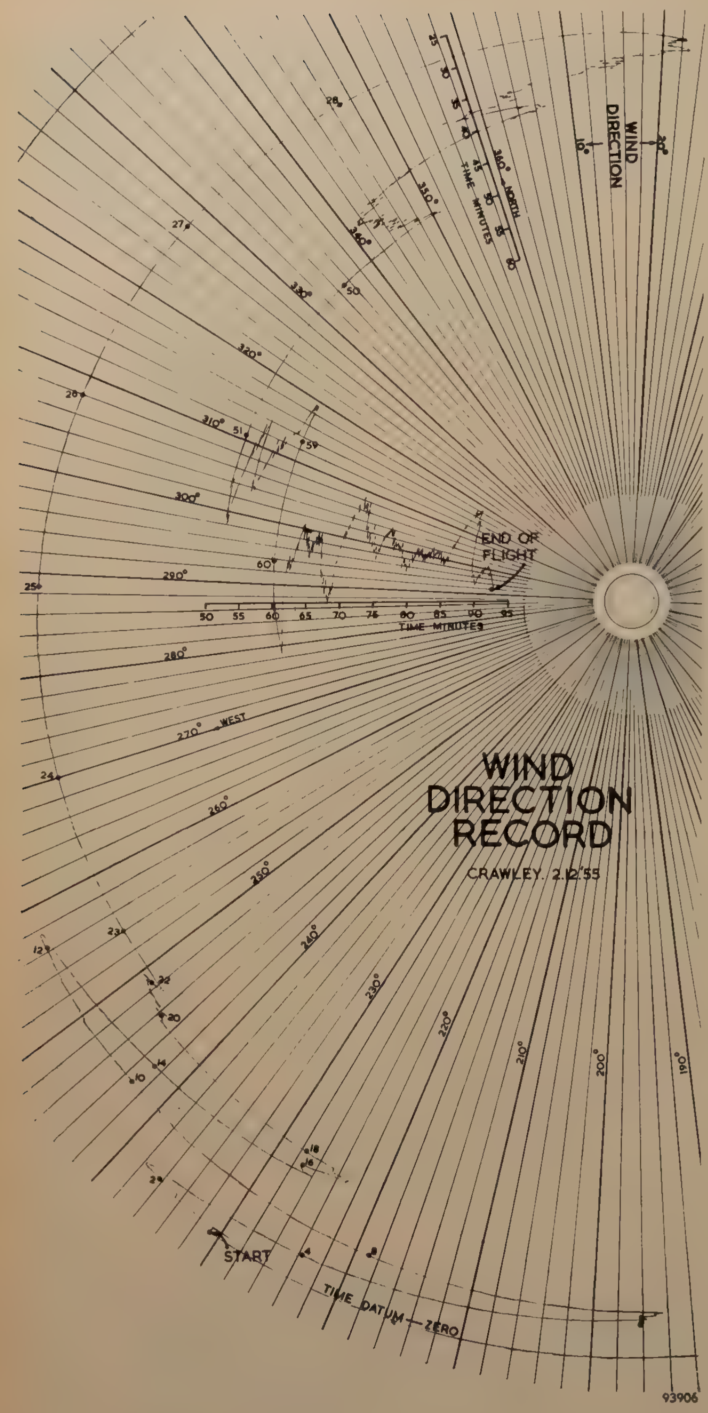
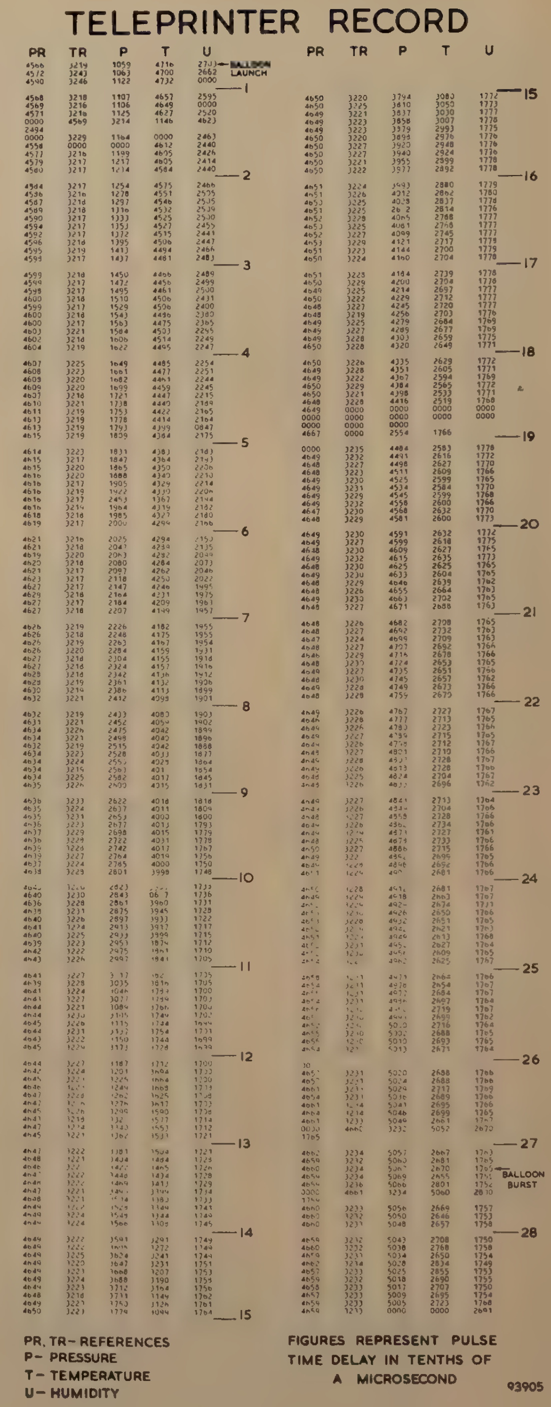


Fig. 7


TELEPRINTER RECORD
PR
TR
P
T
U
BALLOON LAUNCH
BALLOON BURST
93905

PR, TR — REFERENCES
P — PRESSURE
T — TEMPERATURE
U — HUMIDITY

FIGURES REPRESENT PULSE TIME DELAY IN TENTHS OF A MICROSECOND

Fig. 8

Fig. 7. A typical wind direction record obtained from the radar sonde system.

Fig. 8. Typical teleprinter record obtained from the radar sonde system.

nals interposed in the airborne unit switching sequence are used to ensure that the results are printed in the correct columns.

Some typical flight records, which are self-explanatory, are shown in *figures 7, 8* and *9*. The equipment is designed to measure wind speed with an error not exceeding 5 km/hr. The telemetering channels are designed for an error of the order 0.1%, but at present the meteorological instruments themselves contribute somewhat larger errors.

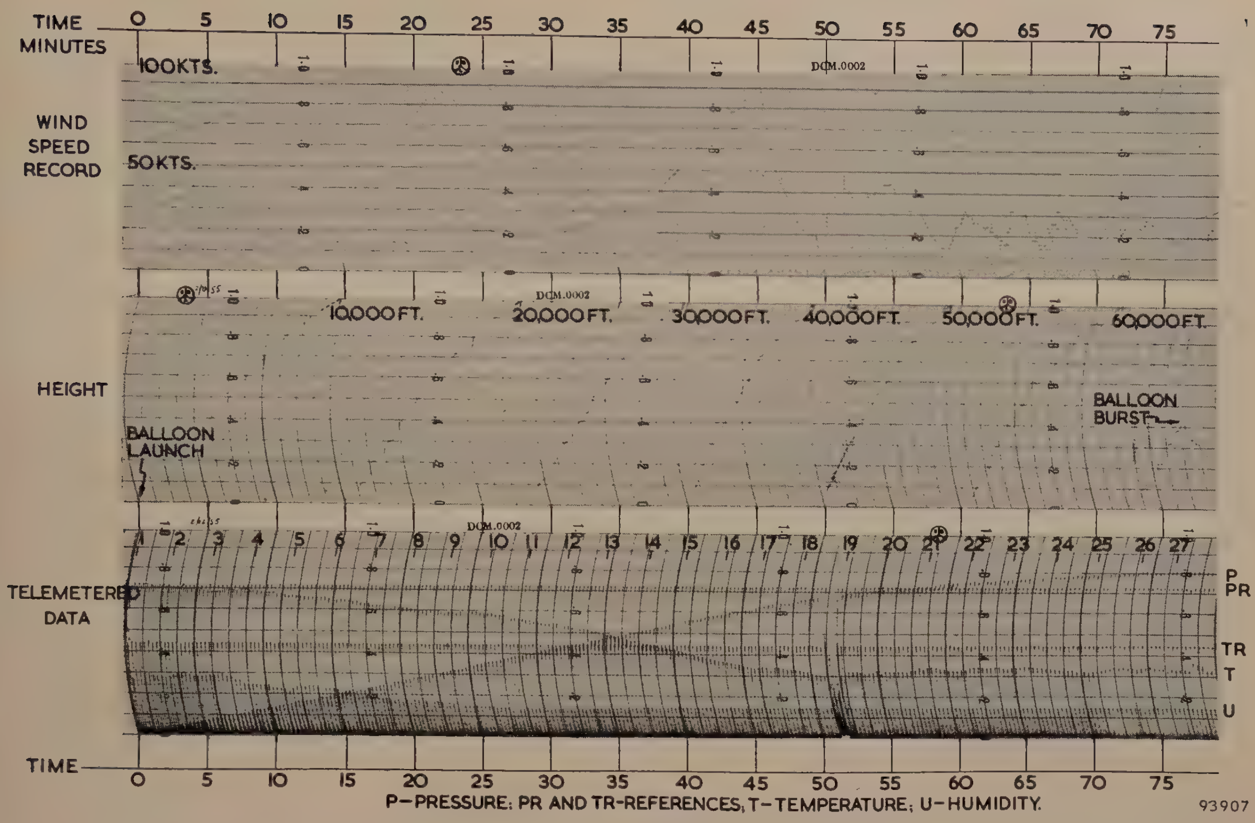


Fig. 9. Example of wind-speed, height and telemetering records obtained from the radar sonde system.

The prototype equipment is at present undergoing flight trials to assess its suitability for routine soundings and research.

The authors are indebted to the Director of the Mullard Research Laboratories, the Ministry of Supply and the Meteorological Office for permission to publish this note.

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DOSIMETRY OF THE VERY WEAK X-RADIATION GENERATED IN TELEVISION RECEIVERS AND X-RAY DIFFRACTION APPARATUS

621.386.82:621.397.62

With many kinds of apparatus in which electron tubes are operated at high voltages, the possible presence of very weak, soft X-radiation (i.e. X-radiation of low penetrating power) in the neighbourhood must be given due consideration. The question arises in such apparatus as X-ray diffraction equipment, formerly found only in research laboratories but now widely used industrially in inspection and production departments. Television receivers, too, can emit X-rays, for in modern large-screen sets the accelerating voltage for the electron beam in the picture tube can be as high as 20 kV at a beam current up to 0.2 mA. Fortunately this X-radiation is so soft that it can be attenuated to harmless intensities by simple means, for example by the 6 mm thick glass shield over the viewing screen, which is needed in any case as protection against implosion of the tube. Nevertheless it is necessary during manufacture to make dosimetric tests to ensure that the intensity of the radiation at the outside of the set in no way endangers the user.

The International Commission for Radiological Protection [1]) has recommended that the dose rate at the outside surface of home television receivers should not exceed 2 milliröntgens per hour (2 mr/h or 0.6 μr/sec). In the future the limit will probably be set lower still, in order to preclude all possibility of genetic hazards. This possible lowering of the limit has been allowed for in the design of the dosimetric apparatus described in this article.

In the case of X-ray diffraction apparatus, the requirements regarding the maximum permissible dose rate outside the useful X-ray beam are less severe, such apparatus being used by so very small a section of the population that genetic considerations do not arise and only the norms for individual protection need be applied. For the industrial use of X-ray equipment the recommended maximum permissible dose rate outside the useful beam is 6 mr/h.

The dose rate of very weak, soft X-radiation, such as that from television receivers, can be checked with Geiger-Müller counter tubes fitted with a window of thin mica (approx. 15 μ). Such tubes are quite sensitive enough for the purpose and the mica window is sufficiently transparent to these soft rays [2]). It has also been found that if the tube has a suitable gas filling, the sensitivity varies only slightly with X-ray wavelength, for the accelerating voltages common in television picture tubes (10-20 kV) [3]). Another advantage of Geiger-Müller counters is their small effective surface (approx. 10 mm diameter). The reading on the meter (for example, a counting-rate meter [2])) then corresponds to the dose rate averaged over the effective surface of the detector. Geiger-Müller counters will therefore be much more sensitive to narrow beams of leakage radiation than the ionization chambers more generally used in dosimetry, which have an effective surface 10 to 100 times larger.

An important problem in radiation measurements is the *calibration* of the meter. This must be done with the aid of a standard dosemeter which has been so designed as to enable the radiation dose to be calculated from the meter reading and the geometrical and electrical data. The standard dosemeter generally used by us for soft radiation, an instrument based on a design by Taylor and Stoneburner [4]), is shown schematically in *fig. 1* [5]). The caption explains the measures taken to make the instrument satisfy the conditions implicit in the definition of the röntgen unit. The dose rate in röntgens per second at the diaphragm D is calculated by dividing the collector current, expressed in e.s.u./sec, by the mass of air, expressed in units of 1.293 mg, in a cylinder having a length equal to the distance between the planes AA' and BB' and having the diaphragm aperture as its base. (A correction needs to be made for the attenuation undergone by the X-rays between the diaphragm and the plane through the centre of the collector.)

These standard dosemeters were made specifically for calibrating the dosemeters used in X-ray therapy, where the dose rates to be measured range from 0.5 to 5 r/sec, or sometimes appreciably higher.

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[1]) Recommendations of the International Commission for Radiological Protection, Brit. J. Radiology, Suppl. No. 6, 1955.

[2]) P. H. Dowling, C. F. Hendee, T. R. Kohler and W. Parrish, Counters for X-ray analysis, Philips tech. Rev. **18**, 262-275, 1956/57 (No. 9).

[3]) See also: T. R. Kohler and W. Parrish, Conversion of quantum counting rate to roentgens, Rev. sci. Instr. **27**, 705-706, 1956 (No. 9).

[4]) L. S. Taylor and C. F. Stoneburner, Radiology **23**, 22, 1934.

[5]) W. J. Oosterkamp and J. Proper, Acta radiologica **37**, 33, 1952.

The dosemeters used for protection purposes are required to measure very much lower dose rates. As we have seen, the permissible maximum for television receivers is 0.6 μr/sec, and in the future it will probably be considerably lower, e.g. 0.1 or 0.2 μr/sec. In order to measure such low dose rates with reasonable accuracy, the instruments used must be calibrated by a standard dosemeter having a sensitivity several million times greater than that of the one illustrated in fig. 1.

The sensitivity of an ionization dosemeter can be increased by increasing the sensitivity of the current measurement. The ionization current is measured either by passing it through a resistor and determining the voltage drop across the resistor with an electrometer, or by causing the current to charge or discharge a capacitor and measuring the change in the voltage on the capacitor in a specific time interval. By using a resistor of higher value, or a capacitor of lower capacitance, the sensitivity of the current measurement can be raised. It is obvious, however, that there is a limit to this.

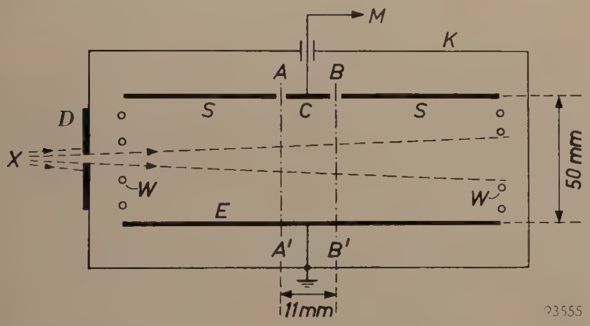

Fig. 1. Schematic cross-section of a standard ionization chamber for dosimetry of soft X-radiation. E and $C+S$ are plane parallel electrodes in a metal, air-filled box K. The X-ray beam X entering the chamber is limited by a round diaphragm D of lead or tungsten. The air in the path of the beam is ionized, chiefly by the fast electrons liberated in air upon primary ionization by the X-rays. These electrons having a fairly large range, penetrate the air around the X-ray beam and cause ionization there too, thus giving rise to a cloud of ions in and around the beam. The electrodes are far enough apart to allow this cloud to form unhindered. The middle section of one of the electrodes, the collector C, is insulated from the outer sections S, which act as a guard ring. Collector and guard ring have approximately the same potential. Owing to the guard ring and to the wires W at both ends of the electrode system, which are held at appropriate potentials, the electric field between AA' and BB' is very uniform, i.e. it has practically no axial component. As a result, provided the field strength is sufficient to draw the ions so rapidly to the electrodes that there is scarcely any chance of recombination, all ions of the same sign, formed between the planes AA' and BB', will travel to the collector. This satisfies the conditions implicit in the definition of the röntgen. The dose rate at the diaphragm, expressed in röntgens per second, is now equal to the collector current in e.s.u. per sec (measured by meter M) divided by the mass of air, expressed in units of 1.293 mg, in a cylinder of length equal to the inter-planar distance of AA' and BB' and of diameter equal to that of the diaphragm aperture. The volume of this cylinder is 0.08 cm³ in the chamber illustrated.

In the standard chamber described, the air volume in which the ionization is measured, and to which the ionization current is proportional, is 0.08 cm³. It can be readily calculated that at a dose rate of 0.15 μr/sec the ionization current in this chamber would be only about 10^{-8} e.s.u./sec $= 3\times10^{-18}$ A. Currents as small as this can no longer be measured by simple means with the required accuracy.

We circumvent this difficulty by calibrating the protection dosemeters with the intermediary of a *substandard chamber* having a volume of about 160 cm³, i.e. 2000 times larger than that of the standard chamber. With a suitably chosen dose rate of the radiation and an appropriate resistor or capacitor it is now possible to calibrate first the substandard chamber with respect to the standard chamber, and then, with the aid of a higher resistance, or a lower capacitance, to check the instruments to be calibrated against the substandard chamber.

In a chamber with such a large volume it is not easy to realize the conditions which must be fulfilled in order to calculate the number of röntgens directly from the geometrical and other data. This is not necessary, however, with the procedure described: all that is required of the substandard chamber is that the reading obtained should be readily reproducible, and that its sensitivity should not vary to any marked extent with the hardness of the X-radiation measured.

For reproducible results, all the ions formed in the chamber must be drawn by the field to the collector. In the first place, therefore, there must be no air currents in the ionization chamber that could carry away the ions, and secondly the electrical field strength must everywhere be high enough to ensure that the ions arrive at the collector before appreciable numbers have had a chance to recombine. The latter condition calls for the most uniform possible field, since it is also desirable to keep the voltage applied to the chamber electrodes as low as possible; an arrangement with flat, parallel electrodes is therefore used. The first condition, however, implies that the chamber should preferably be completely closed, or at all events should have only very small openings. The standard-chamber design sketched in fig. 1, in which the X-rays enter the chamber transversely to the direction of the electric field, is therefore less suitable where a large volume is to be irradiated, as in the sub-standard chamber. The design which we have adopted is illustrated in *fig. 2*. The chamber is in the form of a round box of methyl metacrylate, slightly more than 10 cm in diameter. The radiation enters the box through a "cover" of thin fine-mesh nylon gauze, coated with graphite to make it conductive. The gauze, together with the graphite-coated bottom of the box, constitutes the electrode system; the holes in the gauze are very small so that air currents are avoided. At the same time the threads of the gauze are very thin and the aperture/thread ratio relatively large; hence the gauze gives rise to only slight attenuation of the very soft X-radiation to be measured.

In the standard chamber the air present in the measuring volume is bounded in the direction of the beam by air and the electrodes are outside the X-ray beam; this is not the case in the sub-standard chamber. Although the electrodes in the latter have been made as far as possible "air-equivalent", there is a possibility that not as many electrons will enter the measuring volume from the electrodes as are lost from this volume to the electrodes. It is for this reason that comparison with a standard chamber is desirable. In making this comparison it is necessary that the X-ray beam used should have a constant intensity over the large cross-section of the substandard chamber.

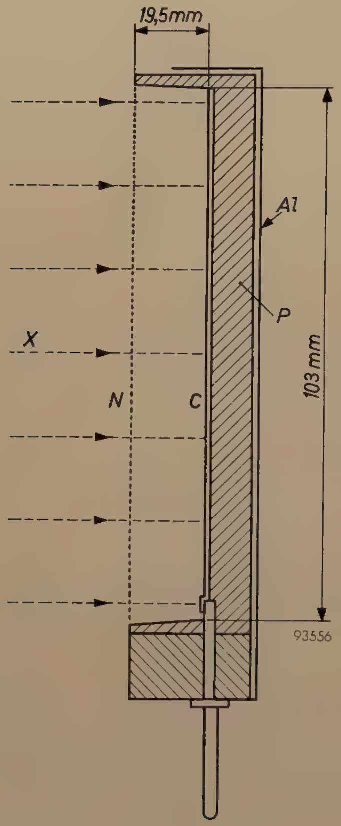

Fig. 2. Sub-standard chamber for dosimetry of extremely weak soft X-radiation. Owing to the large measuring volume (160 cm^3), a measurable collector current is obtained at dose rates as low as 0.1-0.2 μr/sec, which may be found at the outside surface of home television receivers. This sub-standard chamber is used to calibrate Geiger-Müller counters used as dosemeters for protection purposes. *C* graphite layer, acting as collector electrode. *N* electrode of nylon gauze, coated with graphite, through which X-rays enter the chamber. *P* methyl methacrylate box, the outer surface being lined with earthed aluminium foil for electrical screening.

The results of comparing the sub-standard with the standard chamber are shown in *fig. 3* for X-radiation of varying hardness, the latter being expressed in terms of the half-value thickness in aluminium, or by the voltage on the X-ray tube and the filter in the beam.

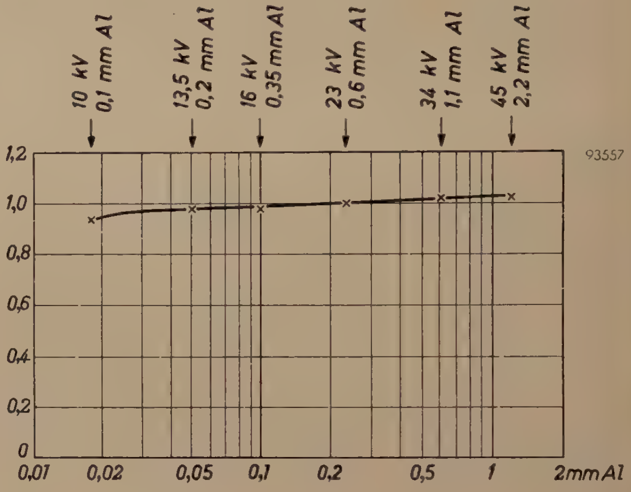

Fig. 3. Calibration curve of the sub-standard chamber illustrated in fig. 2. The ratio of the sensitivity of this chamber to that of the standard chamber in fig. 1, reduced to the same volume of air, is plotted as a function of the hardness of the X-radiation. The hardness is expressed by the thickness of that aluminium layer through which the rays must pass for the dose rate to be reduced by one half (half-value thickness in mm Al). For six different qualities of radiation, the corresponding tube voltages (kV) and filters (mm Al) are also indicated.

A number of Geiger-Müller counters of different dimensions, window thicknesses and gas-fillings were calibrated with the sub-standard chamber at radiations of different hardness; the curves obtained are shown in *fig. 4*. For this purpose the counter tubes were connected to a count-rate meter unit (type PW 4041) which also provides the necessary high voltage supply.

Full deflection in the most sensitive range (300 pulses/min) corresponds to about 0.2 mr/h for counter MX 114, and to about 1.5 mr/h for counter MX 108. It should be recalled that the dose rates to be measured are of the order of magnitude of 0.5 to 2 mr/h. With this in mind and also because it is less dependent upon the hardness of the radiation than the others, the type MX 108 counter is the most suitable for the object in view.

With a Geiger-Müller counter calibrated in this way dose measurements were carried out on three types of television set (17 TX 144A-38, 21 TX 144A-00 and 17 TX 123U-00) operated at about 10% above their nominal anode voltage. At no point on the outside surface of the sets was the dose rate in excess of 0.5 mr/h. In earlier measurements on a similar television set the dose rates were found to be higher, up to 2 mr/h. In this old model, however, the X-rays were mainly caused by the rectifier tubes, type DY 86, in the extra-high tension generator, and only to a slight extent by the picture tube. By providing the rectifier tubes with a lead-rich glass envelope, this unwanted radiation was completely eliminated and thus the safety margin increased.

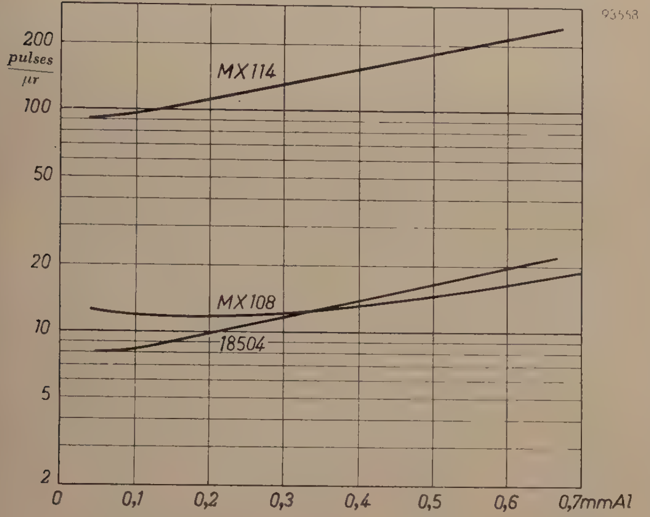

Fig. 4. Calibration curves of three different Geiger-Müller counter tubes, for X-radiation generated at voltages between 10 and 25 kV.
Type 18504: window thickness approx. 10 μ, window diameter 9 mm, gas-filling neon + argon + halogen quencher. The background counts during measurement are 20 pulses/min; useful measurements are still obtained if the signal is roughly equal to the background, i.e. in this case about 2 μr/min, or 0.1 mr/h (at 16 kV).
Type MX 108: window thickness approx. 15 μ, window diameter 17 mm, gas-filling neon + argon + halogen quencher. Background counts 35 pulses/min; lower limit of measurement approx. 0.2 mr/h.
Type MX 114: window thickness approx. 15 μ, window diameter 28 mm, gas-filling neon + argon + halogen quencher. Background counts 70 pulses/min; lower limit of measurement approx. 0.04 mr/h.

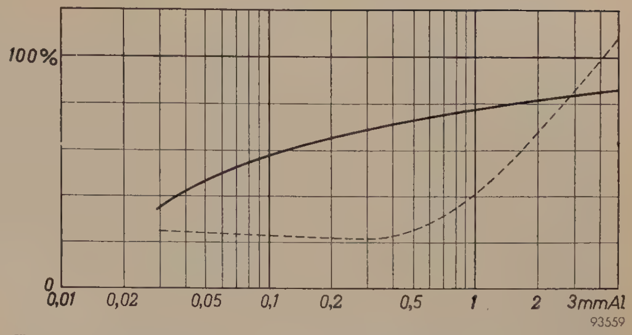

Fig. 5. Sensitivity of an ionization chamber (full curve, approaching 100% for very hard radiation) and of a Geiger-Müller counter type MX 108 (broken curve) as a function of the hardness of the X-radiation.

As already remarked, the recommended maximum permissible dose rate on the outside of X-ray diffraction apparatus is 6 mr/h. This can be measured with sufficient accuracy by ionization instruments (a much used instrument, for example, gives full deflection at 15 mr/h). Voltages up to 50 kV are used in X-ray diffraction apparatus, which means that harder as well as soft radiation is emitted. Above 20 kV the sensitivity of Geiger-Müller tubes increases sharply, whereas that of an ionization chamber remains fairly constant (*fig.* 5). This, too, argues in favour of using an ionization chamber. However, the latter has the drawback, mentioned earlier, of a large effective surface, and therefore it is best to use both instruments in conjunction with each other.

W. J. OOSTERKAMP, J. PROPER and J. J. F. de WIJK.

AN IMPROVED METHOD OF CLEATING

621.981.6

Cleating is a method of riveting widely used in the radio and electronics industry. The object is to effect a mechanical joint between two or more parts, for example between a bush, hub or nut (the cleat) and one or more plates or strips. The cleat has a cylindrical rim which, after it has been pushed through a hole in the plates or strips, is forced outwards by means of a special tool, thus completing the joint. The method is illustrated in *fig. 1*. Cleating can be carried out in two ways: by direct pressure or by applying pressure with the tool spinning. The appropriate tools are represented in *fig. 2*. In the spinning method the tool rotates at a speed of several hundred revolutions per minute. This requires less pressure than the direct pressure method, which is an important consideration with brittle material (ceramics, plastics), but it takes somewhat longer to effect the joint.

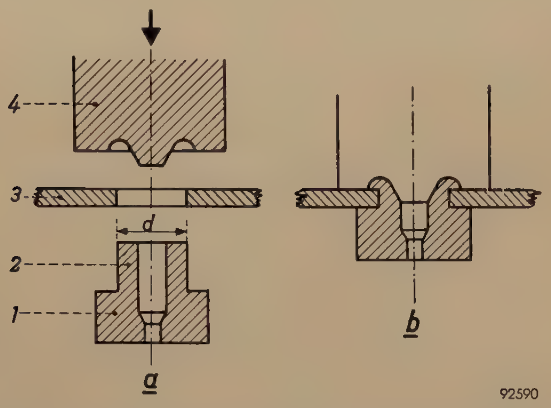

Fig. 1. *a*) *1* cleat, *2* "rim" of cleat, *3* plate with which joint is to be made, and *4* cleating tool for effecting the joint. *b*) Completed joint.

The requirements of a cleated joint are concerned with mechanical strength and appearance. In the process of cleating there is a danger that both the strength and the appearance of the joint will suffer owing to the occurrence of cracks in the rim. (Corrosion may be another cause, but this will not be considered here.)

The cleats are machined from steel, brass or aluminium bar, which are free-cutting only after prior hardening. Hardening can be effected by cold-working, but this in turn reduces ductility and thus increases the likelihood of the rim cracking. For this reason the cleats are subjected, after machining, to an annealing treatment to eliminate the effects of cold-working. It often happens that the annealing process (during which the internal stresses are relieved) gives rise to deformation. If accurate dimensions are necessary, the cleats will therefore have to undergo further mechanical treatment, such as grinding or reaming. The costs involved in these different treatments have led the Metallurgical Laboratory of the Radio-set Factory at Eindhoven, to seek a more efficient solution.

In view of the extent to which the rim of the cleat is plastically deformed during the making of the joint, the occurrence of cracks is not surprising. In the case of a rim of diameter $d = 4$ mm (fig. 1*a*), a radial compression of about 15% occurs at point A (*fig. 3*) and a tangential elongation of about 25%; at point B there are radial and tangential elongations of as much as 70% and 100%, respectively. The fact that the metal can withstand such (by normal standards) large plastic deformation is due to the introduction during the cleating process of compressive components which act at right-angles to the

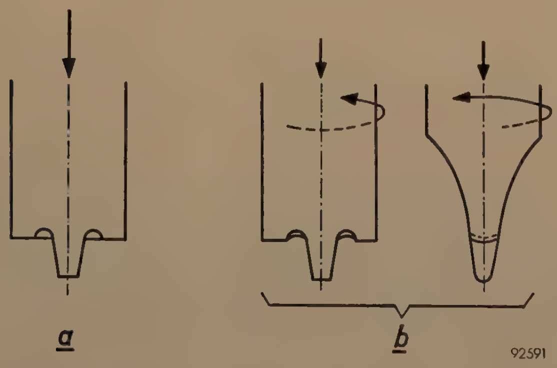

Fig. 2. *a*) Tool for direct pressure method (solid of revolution). *b*) Tool for spinning method (front and side views).

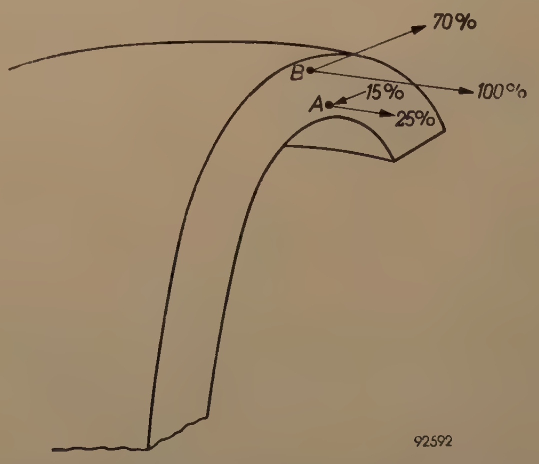

Fig. 3. Section of rim after cleating by old method; external diameter (before cleating) 4 mm. At A the radial and tangential deformations are about 15% and 25% respectively; at B about 70% and 100%.

tensile components. (An analogous state is produced in deformation processes such as cold-rolling and riveting.)

The first stage in the approach to the problem was, therefore, to design the cleat and the tool in such a way as to result in a smaller tangential deformation and, at the same time, greater pressure in radial directions. This implies keeping the material of the rim more bunched together. With that object in view the profile of the tool was modified, and experiments showed that the profile indicated in *fig. 4* produced the best results. It was also found better to make the rim of the cleat slightly thicker than before. Apart from questions of design, various kinds of materials and different lubricants were included in the investigations; the optimum duration of the cleating process was determined and, for the spinning method, the optimum speed of revolution. All experiments were carried out in accordance with a statistically planned schedule ¹).

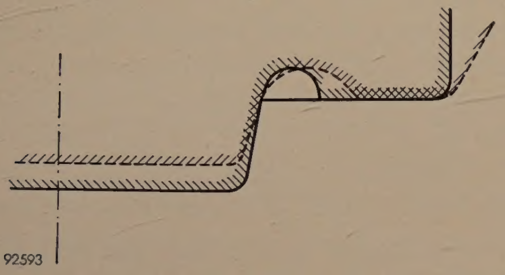

Fig. 4. Old profile (dashed) and new profile (full line) of cleating tool.

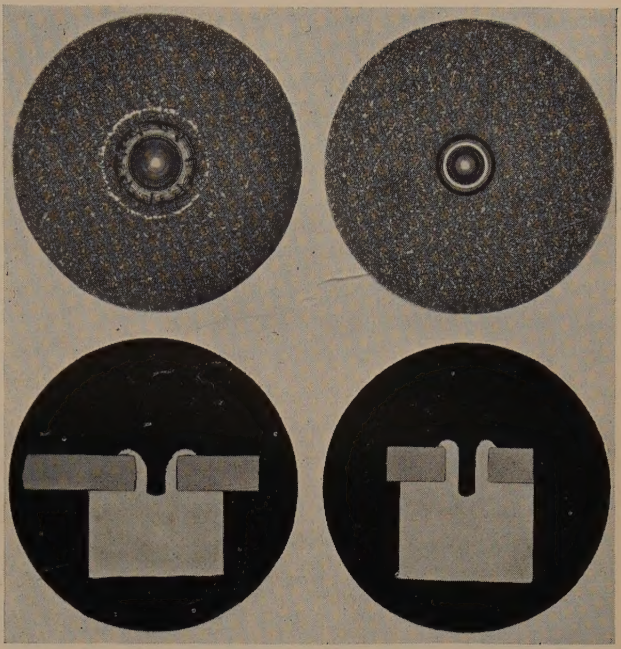

Fig. 5. Cleated joints seen from above and in section. Material: brass. Magnification: 3 ×. *Left:* example of joint made by old method and which frequently had to be rejected because of cracked rim. *Right:* reproducible cleated joint made by improved method.

The result was an appreciable improvement in the appearance of the cleated joints — as demonstrated in *fig. 5* — and in their mechanical strength, achieved without the need for the various pretreatments referred to above.

H. E. DEELMAN.

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¹) H. E. Deelman, Sigma **3**, 26-29, 1957 (No. 2).

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS BY THE STAFF OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk * can be obtained free of charge upon application to Philips Electrical Ltd., Century House, Shaftesbury Avenue, London W.C. 2.

2494: P. Jongenburger: Energy of formation of vacancies in copper and gold (Phys. Rev. **106**, 66-69, 1957, No. 1).

From the anomalous rise of the thermal expansion near the melting point, a value of about 0.7 eV for the energy of formation of vacancies in copper and gold is found.

2495: H. A. Klasens: Elektroluminescentie (Ingenieur **69**, E.77-E.80, 1957, No. 23). (Electroluminescence; in Dutch.)

The construction of an electroluminescent panel is described. The properties of electroluminescent phosphors and the mechanism of electroluminescence are briefly discussed. Possible applications of electroluminescence are mentioned.

2496: J. L. Meijering: Calculation of the nickel-chromium-copper phase diagram from binary data (Acta metallurgica **5**, 257-264, 1957, No. 5).

In the solid state the Ni-Cr-Cu system shows a three-phase equilibrium between a Cr-rich b.c.c. phase and two f.c.c. phases rich in Ni and in Cu respectively. This rather unexpected feature (Ni and Cu being completely miscible) is examined thermodynamically, using the regular approximation. The most probable values of the interaction parameters are obtained from data on the binary boundary systems. The resulting ternary diagram is indeed of the type found experimentally.

2497: G. Diemer, H. A. Klasens and P. Zalm: Voltage dependence of electroluminescence (J. Electrochem. Soc. **104**, 130 C, 1957, No. 6).

Re-examination of the results of Lehmann shows that they fit an exp $(-b/V^{\frac{1}{2}})$ brightness law over a larger range than suggested by this observer. This is in agreement with measurements by the present authors.

2498: A. van Weel: The design of phase-linear intermediate-frequency amplifiers (J. Brit. Instn. Rad. Engrs. **17**, 275-286, 1957, No. 5).

Data are given for the design of i.f. amplifiers with flat group-delay characteristics for combinations of from one to six tuned circuits. Both staggered-tuned single circuits and combinations of band filters are considered. Figures of merit are calculated and compared with the figures for networks based on flat-amplitude design.

2499: K. Compaan and Y. Haven: Correlation effects in diffusion problems in solids (Trabajos III reunión internacional sobre reactividad de los sólidos, Madrid, April 1956, section I, pp. 255-269; published 1957).

The correlation, which in many cases exists between the consecutive jumps of a radioactive tracer diffusing into solids, affects in certain types of diffusion mechanisms in ionic solids the diffusion constant of tracers, but not the contribution of these ions to conductivity. As a consequence, the relation of Einstein contains a correlation factor f which depends on the crystal structure as well as on the mechanism of ionic transport. It will be shown how an accurate test of the relation of Einstein can give information on the mechanism of ionic transport through solids. The following examples are discussed: diffusion of Na^+ through NaCl, Ag^+ through silver halide, Li through germanium and sodium through glass.

2500: G. H. Jonker: Compounds in the system Li_2O-TiO_2 and their stability (Trabajos III reunión internacional sobre reactividad de los sólidos, Madrid, April 1956, section I, pp. 413-421; published 1957).

In the oxide system Li_2O-TiO_2 three compounds are found: Li_2TiO_3, $Li_4Ti_5O_{12}$ and $Li_2Ti_3O_7$. The first compound can be prepared in an unstable unordered form with NaCl structure but prolonged heating leads to a stable orthorhombic pseudohexagonal super-structure. For the second compound, which has a spinel structure, it is established that the composition is not $Li_4Ti_7O_{16}$ as has been mentioned in the literature but a more normal one with a metal-to-oxygen ratio of 3 : 4. The third compound has an unknown crystal structure and can be obtained e.g. from the former one by evaporation of Li_2O at high temperature.

2501: A. L. Stuijts and H. B. Haanstra: Grain growth in a ceramic material, studied by means of electron microscopy (Trabajos III reunión internacional sobre reactividad de los sólidos, Madrid, April 1956, section I, pp. 671-701; published 1957).

Description of a replica technique whereby it is possible to make electron-microscope studies of changes in small pre-specified regions of a surface. Observations can be repeated on exactly the same region without damaging the surface and allowing treatment of the surface in between each observation. A series of electron micrographs are shown of a ceramic material ($BaFe_{12}O_{19}$) whose surface shows large micro-relief and which is somewhat porous. The photographs show that it is possible to follow changes in a group of crystallites after sintering for various times and at various temperatures.

2502: G. H. Jonker, H. P. J. Wijn and P. B. Braun: A new class of oxidic ferromagnetic materials with hexagonal crystal structures (Proc. Instn. Electr. Engrs. **104 B**, suppl. No. 5, 249-254, 1957).

Several new groups of ferromagnetic oxides have been found. They have rather complicated chemical compositions and can be obtained as reaction products of Fe_2O_3, BaO and MeO in various proportions, where Me denotes, in general, an element of the first transition group, or either Mg or Zn. The crystal structures of these new compounds can be described in the hexagonal system and are related to the magnetoplumbite structure. The crystal anisotropy of many of these hexagonal compounds is such that, depending on the chemical composition, the spontaneous magnetization in each crystal is oriented either parallel or perpendicular to the hexagonal axis. In the latter case the magnetization can fairly easily be rotated in the basal plane. Polycrystalline sintered samples of such compounds show an initial permeability of about 10; the permeability remains substantially constant up to about 1000 Mc/s, so that these new materials extend the frequency range where ferromagnetic oxides can be advantageously used as core materials to frequencies much higher than is now possible with ferrites having cubic crystal structures. An earlier paper on these materials has been published in Philips tech. Rev. **18**, 145, 1956/57 (No. 6).

2503: E. W. Gorter: Saturation magnetization of some ferrimagnetic oxides with hexagonal crystal structures (Proc. Instn. Electr. Engrs. **104 B,** suppl. No. 5, 255-260, 1957).

Anderson's treatment of super-exchange yields a qualitative rule for the dependence of interaction on angle Me-O-Me. Using this rule, and assuming a longer distance to lead to a weaker interaction, low-temperature saturation magnetizations for ferrimagnetic oxides with known crystal structures can often be predicted. The results obtained for some of the materials described elsewhere (No. **2502**, these Abstracts), i.e. $Ba_2Me_2^{II}Fe_{12}O_{22}$ (**Y**), $Ba_3Me_2^{II}Fe_{24}O_{41}$ (**Z**), and $BaMe_2^{II}Fe_{16}O_{27}$ (**W**) (in which Me^{II} may be Mn, Fe, Co, Ni, Mg, or Zn), together with those for $BaFe_{12}O_{19}$ (**M**) and $KFe_{11}O_{17}$, with related crystal structures, are compared with the results of saturation-magnetization measurements down to 20 °K. It is shown that very small differences in crystal structure, such as exist between $KFe_{11}O_{17}$ and **M**, and between **M** and **Y**, can result in drastic differences in spin orientations of neighbouring ions. In particular for **Y**, the experimental data yield some insight into the distribution of the divalent Me ions among the various lattice sites. The crystal structure of **Z** is composed of alternating blocks of **M** and **Y**, that of **W** is composed of alternating blocks of **M** and S (spinel). The saturation magnetizations are obtained by adding those of the composing blocks.

2504: H. Koelmans and A. P. M. Cox: Luminescence of modified tin-activated strontium orthophosphate (J. Electrochem. Soc. **104,** 442-445, 1957, No. 7).

The introduction of Al, Zn Mg, Ca, or Cd in $Sr_3(PO_4)_2$ produces a new crystal phase which is probably isomorphous with $\beta Ca_3(PO_4)_2$. Activated with tin this Sr-orthophosphate gives a strong luminescence with a maximum at about 6300 Å under excitation with 2537 Å.

2505: H. Koopman, J. H. Uhlenbroek and J. Daams: New s-triazine herbicides (Nature **180,** 147-148, July 20, 1957).

Note on preparation of 2-alkoxy and 2-alkylthio 4,6-dichloro-s-triazines. It is found that the chlorine atom can be replaced by an alkylamino, alkyloxy or alkylthio group. Certain of these compounds show strong phytotoxic activity. Some preliminary tests are described.

2506: G. H. B. Teunissen, O. Bosgra and J. H. G. Wilson: Praktijkervaringen met levend, avirulent hondeziektevirusvaccin (T. Diergeneesk. **82**, 493-506, 1957, No. 14). (Practical experiences with live avirulent canine-distemper virus vaccine; in Dutch.)

Two series of tests on the vaccination of dogs against distemper and hard-pad disease. In all, 584 dogs from surroundings where canine-distemper is of frequent occurrence, were vaccinated with live avirulent canine-distemper virus vaccine. No data were obtainable with regard to 17 of these dogs. The subsequent history of the remaining 567 was traced for a considerable period, some up to two years after vaccination. Results show that puppies can, without danger, be immunized with live avirulent canine-distemper virus vaccine against both distemper and hard-pad disease virus infections.

2507: J. A. Kok: Doorslagverschijnselen in vloeibare isolatoren (Ingenieur **69,** E.87-E.92, 1957, No. 27). (Electric breakdown in liquid insulators; in Dutch.)

Polarizable material drifts towards a place of maximum stress by the action of transverse gradient — E^2 — forces and forms a bridge, if $r^3E^2 > \frac{1}{4}kT$. The critical diameter of the particles at $T =$ 300 °K is for $E = 22$ kV/mm: $2r = 50$ Å and for $E = 94$ kV/mm: $2r = 20$ Å. The breakdown strength of Shell Diala C oil was increased considerably by purification in an electrostatic Cottrell filter.

2508: J. P. L. Bots: Preparation of pure lactulose (Rec. Trav. chim. Pays-Bas **76,** 515-518, 1957, No. 6).

A simple method is described for the preparation of lactulose octa-acetate by acetylation of the reaction product obtained by treating lactose with lime. Pure lactulose was prepared by de-acetylation of lactulose octa-acetate with 0.1 *N*-HCl at 71 °C.

2509: J. S. C. Wessels: Studies on photosynthetic phosphorylation, I. Photosynthetic phosphorylation under anaerobic conditions (Biochim. biophys. Acta **25,** 97-100, 1957, No. 1).

The photochemical esterification of inorganic phosphate into adenosine triphosphate by chloroplasts was investigated under anaerobic conditions in the presence of either vitamin K_3 or flavin mononucleotide. Evidence is presented in support of the conclusion that vitamin K_3 and flavin mononucleotide are involved in separate pathways for photosynthetic phosphorylation. A tentative scheme for the generation of adenosine triphosphate in chloroplasts, consistent with this conclusion, is given.

2510: J. M. Stevels: Quelques remarques sur la résistivité du verre en courant continu (Silicates industriels **22**, 325-335, 1957, No. 6).

An attempt is made to discuss the well-known equation for the specific resistance ϱ of glasses as a function of the temperature T: $\log \varrho = A + B/T$, by a model of potential wells separated by potential barriers. Formulae are given for the constants A and B, for silicate glasses containing only one kind of network-modifying ions, relating these constants with quantities such as jump distance, height of the potential barriers, concentration and vibration frequency of the network-modifying ions. The limits of the validity of the above equations in terms of the temperature and the electric field applied is also discussed. Finally the relation between A and B and the coherence of the Si-O network is discussed in an extensive way. It is found that the height of the potential barriers (activation energies of the moving network-modifying ions) is not a smooth function of the degree of cohesion of the network, but shows bends. The physical background of these bends is discussed.

2511: M. J. Sparnaay: Attractive forces between flat plates (Nature **180**, 334-335, Aug. 17, 1957).

Note concerning measurements using metal plates instead of the glass or quartz plates used previously. The results show that Casimir's d^{-4} relation is not contradicted.

R 328: G. Braun: Mathematical treatment of a typical zone-melting process (Philips Res. Rep. **12**, 385-414, 1957, No. 5).

This paper deals with the mathematical theory of a typical example of a zone-melting process as described by Van den Boomgaard in a preceding Report (No. **R 275**, these Abstracts). The process in question aims at the realization of a most homogeneous distribution of a solute (which may be volatile) in an ingot. This is effected by a large number of identical steps and amounts to an extension of the procedure proposed by Pfann and Reiss. The intermediate distributions tending to the limiting one are considered in detail, as well as the number of steps necessary to arrive at such a distribution. The mathematics determine the asymptotic behaviour of the solution of a system of differential-difference equations by means of a generating function.

R 329: G. Brouwer: Graphical analysis of the temperature dependence of the electronic population in semiconductors (Philips Res. Rep. **12**, 415-422, 1957, No. 5).

The distribution of electrons and holes in semiconductors and its variation with temperature may be derived by means of a graphical approximation presented in this paper. The method is based directly on the electronic reaction equations in the equilibrium.

R 330: G. D. Rieck: The texture of drawn tungsten wires (Philips Res. Rep. **12**, 423-431, 1957, No. 5).

According to a paper by Jeffries, which although old, is still referred to in textbooks, drawn tungsten wire has a texture with the [110] axis of the grains in the wire direction and their (001) planes parallel to the surface of the wire. It is proved, however, with the aid of X-ray diffraction measurements, that the tungsten wire has the generally accepted normal fibre texture with a random orientation of the (001) planes around the [110] fibre axis.

R 331: J. S. van Wieringen and A. Kats: Paramagnetic resonance and optical investigation of silicate glasses and fused silica, coloured by X-rays (Philips Res. Rep. **12**, 432-454, 1957, No. 5).

Silicate glasses containing alkali oxides (or mixtures of alkali and alkaline earth oxides) are irradiated with X-rays both at room and liquid-nitrogen temperature. Colour centres are produced whose optical and paramagnetic resonance properties have been studied. All silicate glasses show two paramagnetic resonance peaks due to two different colour centres containing electrons and holes, respectively. From the line widths at 9500 and 24 000 Mc/s it follows that both centres have a spin $\frac{1}{2}$ and are in local electric fields of very low symmetry. Comparison with the optical measurements shows that the electron centre is likely to be connected with the optical absorption band between 4150 Å and 4900 Å and the hole centre with the band at 3100 Å. Similar measurements are made on fused silica irradiated with X-rays at room temperature. Again two paramagnetic resonance peaks are found, ascribed to electrons and holes, respectively. In the optical spectrum three absorption bands are developed. The behaviour of fused silica depends strongly on its water content. After irradiation the samples containing water show only the resonance peak of the electron centre and the optical absorption band at 2150 Å; the hole peak and the other two bands are absent or extremely weak.